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ELEMENTS OF
OPTICAL MINERALOGY

BY THE SAME AUTHORS

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ELEMENTS OF
OPTICAL MINERALOGY

AN INTRODUCTION TO
MICROSCOPIC PETROGRAPHY

BY

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AND
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Entirely rewritten and much enlarged by
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SECOND EDITION

PART II. DESCRIPTIONS OF MINERALS

WITH SPECIAL REFERENCE TO THEIR OPTIC AND MICROSCOPIC CHARACTERS

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By ALEXANDER N. WINCHELL

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PREFACE

In the first edition of this work the descriptions of minerals were arranged alphabetically so far as possible without losing the obvious advantages of keeping isomorphous groups together. It was thought that this arrangement, aided by cross references, would be of material assistance to the student. Actual experience, however, has shown that some students did not even know that the arrangement was alphabetical, and others rarely, if ever, used the alphabetical arrangement when consulting the book. Somewhat reluctantly, and only after long experience, the author was forced to conclude that the arrangement did not serve its purpose successfully.

When the second edition was undertaken the question of a satisfactory arrangement became urgent. A plan of arranging the minerals in isoaxial, uniaxial, and biaxial divisions with each division arranged in the order of increasing refringence (but still retaining the isomorphous groups) was thought desirable in a book devoted to "Optical Mineralogy," because this arrangement is based on optic properties. However, after consultation with several of his colleagues, to whom sincere thanks are due for thoughtful advice freely and courteously given, and after writing about one-third of the manuscript in this order, the author finally concluded to reject it, also, in favor of the scientific arrangement first worked out by Dana and afterward modified more or less by later writers. One reason for this decision was the fact that some isomorphous groups do not fit into the rejected arrangement, and another was the difficulty of properly classifying some minerals like tridymite, catapleite, laubanite, etc., which are uniaxial or not depending upon slight variations in temperature.

The descriptions of minerals are arranged according to the familiar scientific classification of Dana, modified somewhat in accordance with advancing knowledge and good usage. Thus, the major divisions of the classification are the same in substance and in order as those recommended by the Committee on Nomenclature and Classification of the Mineralogical Society of America in its report published in the

March, 1924, number of the *American Mineralogist*. However, the writer prefers to group the nitrates with the carbonates, rather than with the phosphates, both because they are relatively simple like the carbonates, and because some nitrates are crystallographically very similar to certain carbonates, as shown especially in the case of nitratite ($NaNO_3$) and calcite ($CaCO_3$), and also in the case of niter (KNO_3) and aragonite ($CaCO_3$). The minor divisions are also in general agreement with recent good usage, but differ in some respects from those of any of the recognized authorities. It is hoped that they will be found reasonably consistent and satisfactory.

All natural minerals [1] are included in this work, if their optic properties are sufficiently well known to permit their identification microscopically. Many omissions will doubtless be discovered, but the writer has spent many months searching all available literature for data (unfortunately almost never indexed), and trusts that he has achieved a reasonable measure of success.

As a convenience to the student a few of the commonest opaque minerals are included, even though optic data are necessarily lacking, in general, for such substances; but no attempt is made to describe all the minerals which are opaque in their smallest visible particles or flakes. Full information regarding them may be found in recent works by Murdoch, Davy and Farnham, and Schneiderhöhn.

The minerals are arranged in accordance with the following outline classification. Details may be found in the table of contents.

I. Elements
II. Sulphides
III. Halides
IV. Oxides
V. Carbonates
VI. Borates
VII. Sulphates
VIII. Phosphates
IX. Columbates
X. Silicates

The description of each mineral is given in the following order:

Name
Crystal system (axial elements)
Chemical composition (Comp.) usually expressed merely by a formula
Physical characters (Phys. Char.), including crystal habit, twinning, cleavage, hardness (H.), specific gravity (G.), fusibility (F.), and solubility

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[1] The author's description of "The Optic and Microscopic Characters of Artificial Minerals," *No. 4, Sci. Series, Univ. Wis. Studies*, may be obtained from the University Editor, Madison, Wis.

Optic properties[2] (Opt. Prop.), including optic orientation, extinction angles, refringence, birefringence, sign, optic angle, dispersion, color, pleochroism, and absorption
Inclusions (Incl.)
Inversions (Inver.)
Alterations (Alter.)
Occurrence (Occur.)
Diagnostics (Diag.)

In the description of each group of minerals the order adopted is essentially the same as just outlined, with the addition of a paragraph, where needed, regarding

Classification (Class.)

The condensed style of writing formulas, as illustrated by $CaCO_3$ rather than $CaO \cdot CO_2$, has been chosen deliberately and used consistently, except for some minerals of complex and uncertain formulas. Two reasons for this choice deserve mention. First, recent X-ray studies have shown that the atoms in crystals are not grouped as suggested by $CaO \cdot CO_2$, but are arranged as indicated, for example, by $CaCO_3$. Second, in silicates, and in other complex substances, isomorphous relationships are much more easily seen between molecules written in the condensed form, modified slightly, than between molecules written in the extended form. This may be illustrated by a few examples, as follows:

Mineral	Extended Formula	Condensed Formula
Plagioclase	$Na_2O \cdot Al_2O_3 \cdot 6SiO_2$ $CaO \cdot Al_2O_3 \cdot 2SiO_2$	$NaAlSiSi_2O_8$ $CaAlAlSi_2O_8$
Pyroxene	$CaO \cdot MgO \cdot 2SiO_2$ $Na_2O \cdot Al_2O_3 \cdot 4SiO_2$	$CaMgSi_2O_6$ $NaAlSi_2O_6$
Melilite	$2CaO \cdot Al_2O_3 \cdot SiO_2$ $2CaO \cdot MgO \cdot 2SiO_2$	$Ca_2AlAlSiO_7$ $Ca_2MgSiSiO_7$
Chlorite	$3MgO \cdot 2SiO_2 \cdot 2H_2O$ $2MgO \cdot Al_2O_3 \cdot SiO_2 \cdot 2H_2O$	$Mg_2MgSiSiO_7 \cdot 2H_2O$ $Mg_2AlAlSiO_7 \cdot 2H_2O$

The writer has argued[3] that the calcium atom is not interchangeable freely with other divalent atoms in crystal space-lattices because it is considerably larger than the latter; in simple molecules such as

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[2] Of course these are physical characters, but for emphasis they are treated separately.

[3] *Science*, LXI, 1925, p. 553.

$CaCO_3$, magnesium proxies for calcium, or *vice versa*, only to a slight extent, such as 2 to 10 per cent; in larger molecules, such as $CaMgSi_2O_6$, magnesium may proxy for calcium to a larger extent; at *high temperature* in large molecules magnesium may even proxy for calcium in all proportions, so as to make a continuous isomorphous series. In certain minerals, which contain both calcium and magnesium (or ferrous iron) in large amounts, it is easy to show that no isomorphous series exists, but rather a double compound, such as illustrated by dolomite, $CaMg(CO_3)_2$. Accordingly, in this book, simple formulas containing (Ca,Mg), (Ca,Fe), (Mg,Ca), (Fe,Ca), etc., are not used except when the second element is quite limited in possible tenor. Even in complex molecules the same condition is not rare. For example, the formula of allanite is often written $H(Ca,Fe'')_2(Al,Ce,Fe''')_3Si_3O_{13}$, but a study of the analytical data shows that $HCaFe''(Al,Ce,Fe''')_3Si_3O_{13}$ is better, and the common intimate association of allanite and epidote indicates that an isomorphous series does not exist between them, although the tenor of Ce_2O_3 and Fe_2O_3 probably varies from zero to a maximum. Similarly, the formula of homilite seems to be $Ca_2FeB_2Si_2O_{10}$ that of axinite $H(Fe,Mn)Ca_2Al_2BSi_4O_{16}$, etc.

The ordinary practise of considering that a natural mineral is a definite chemical compound is quite misleading, since such a condition is rare among minerals, nearly all of them being composed of two or more chemical compounds in mutual crystal solution. Since minerals vary thus in composition, they also vary in optic properties, and it is therefore incorrect to assume that any mineral (with some exceptions, such as quartz) has optic properties any one of which can be assumed to have any *single* value of any precision. For example, each index of refraction of a definite pure chemical compound, under given temperature and pressure conditions, varies so little in different samples that the value may be considered absolutely constant to the fourth or fifth decimal place; on the contrary, each index of refraction of almost any mineral is not constant even to the third decimal place, because of variations in composition. Therefore, the general rule in this book is to give the values of indices of refraction of minerals only to the third decimal place, and, whenever possible, to express known variations in the indices and their relations to variations in composition.

It is obvious that a work of this kind is largely a compilation of all available data, and in its preparation the writer has made free use of the standard publications on the subject, including especially:

E. S. Dana and W. E. Ford: System of Mineralogy, with three appendices, 1892–1915.
C. Doelter: Handbuch der Mineralchemie, vol. I–III, 1912–1922.
P. Groth: Chemische Krystallographie, vol. I II, 1906 and 1908.
C. Hintze: Handbuch der Mineralogie, vol. I and II, 1897-1915.
A. Lacroix: Minéralogie de la France, vol. I–V, 1893–1913.

For summaries of recent literature the writer has found especially valuable the abstracts published in:

American Mineralogist, vol. 1–11, 1916–1926.
Mineralogical Abstracts, vol. 1 and 2, 1920-1926.
Neues Jahrbuch für Mineralogie, 1910–1926.
Zeitschrift für Kristallographie, vol. 51–60, 1913–1924.

For data on optic properties he has used the references already cited and also:

H. Dufet: Recueil de Données Numériques, Vol. II, 1899, and Vol. III, 1900.
E. S. Larsen: Microscopic Determination of the Nonopaque Minerals, 1921.
H. R. Landolt and R. Bornstein: Physikalisch-chemische Tabellen, 5 Aufl., 1923.
L. J. Spencer: Tables Annuelles Internationelles de Constantes, etc., vol. I–V, for 1910–1922, published in 1912–1926.

No attempt is made in this volume to give the source of all the data which are included; so far as they are derived from the standard reference works already cited, it is considered unnecessary to cite these repeatedly. On the other hand, the writer has aimed to give references to the source of all data from unusual sources or from current literature.

It is a pleasure to acknowledge the kindly assistance received by the writer from many of his colleagues in the preparation of this book, either in the way of advice or data; the following persons have been particularly helpful:

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Dr. F. E. Wright of the Geophysical Laboratory.

Many of the diagrams, especially prepared for this book, have been made under the writer's direction by his son, Alexander Vaughn Winchell.

The drawings showing the optic orientation of the various kinds of plagioclase in stereographic projection (Figs. 265, 267, 269, 272, 275 and 277) were prepared by M. D. Harbaugh on the basis of the new data published recently by Duparc and Reinhard in their important monograph on the plagioclase feldspars (*Mem. Soc. Phys. Hist. Nat. Genève*, XL, 1924, fasc. 1.). Several diagrams of the optic elements and extinction angles of the plagioclase feldspars (Figs. 228–230, 232, 238–243, 266, 268, 270, 273, 276 and 278) have been redrawn from the illustrations of the same authors.

The author and publishers are under obligations to the Editor of the *American Mineralogist* for the loan of the zinc etchings for Figs. 123, 126, 130, 281, 316, 318, 319, 323, 325 and 330; they are under similar obligations to the Editor of the *Journal of Geology* for the use of cuts of Figs. 244 to 249.

It has been a matter of surprise and pleasure to discover in the course of the preparation of this book the value and interest of such work. The writer believes that the book is not merely a compilation, but includes also much new information derived from comparative studies of existing data. Some of this new information has been presented in various articles published recently in the *American Journal of Science* and the *American Mineralogist*. It includes new ideas regarding the chemical constitution of many of the isomorphous groups of rock-forming silicates, as well as new correlations between variations in composition and in optic properties in the same groups. These have been included in the present work chiefly in the form of diagrams, which are expected to be of material assistance in petrographic work.

ALEXANDER N. WINCHELL.

MADISON, WISCONSIN.

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LIST OF ABBREVIATIONS AND SYMBOLS

(Chemical symbols and names of periodicals not included.)

A, B = optic axes of biaxial crystals.
a = front and rear crystal axis.
α = angle between crystal axes b and c.
Ab = albite.
Alter. = alterations.
An = anorthite.
b = right and left crystal axis.
β = angle between crystal axes a and c.
°C. = degree Centigrade.
c = vertical crystal axis.
γ = angle between crystal axes a and b.
Char. = characters.
Class. = classification.
Cn = celsian.
Comp. = composition.
D (after index of refraction) = " monochromatic " light of the D doublet.
Diag. = diagnostics.
E = extraordinary ray.
2E = the apparent optic axial angle measured in air.
ϵ = index of refraction for the extraordinary ray.
F. = fusibility.
G. = specific gravity.
H. = hardness.
2H = the apparent optic axial angle measured in oil.
Hex. = hexagonal.
Incl. = inclusions.
Inver. = inversions.
Isom. = isometric.
Li (after index of refraction) = lithium (red) light.
λ = wave length of monochromatic light.
m = an indefinite number.
μ = a thousandth of a millimeter, or a micron.
$\mu\mu$ = a millionth of a millimeter.
Max. = maximum.
Mono. = monoclinic.
N = index of refraction.
Na (after index of refraction) = sodium (yellow) light.
N_e = index of refraction for the extraordinary ray.
N_g = greatest index of refraction = γ of German writers.
N_m = intermediate (" mean ") index of refraction = β of German writers.
N_o = index of refraction for the ordinary ray.
N_p = least (" petty ") index of refraction = α of German writers.

n = an indefinite number

O = ordinary ray.

Occur. = occurrence.

Opt. Prop. = optic properties.

Or = orthoclase.

Orth. = orthorhombic.

Phys. Char. = physical characters.

Prop. = properties.

ρ = red (light).

$\rho > v$ or $\rho < v$ (after optic angle) signifies that the optic axial angle in red light is greater than or less than the optic angle in violet light.

Tetr. = tetragonal.

Tl (after index of refraction) = thallium (green) light.

Tric. = triclinic.

Trig. = trigonal or rhombohedral.

2V = the true angle between the optic axes.

v = violet (light).

X = the vibration direction of the fastest ray = $\mathfrak{a}$ of German writers.

X > Y, X < Z, etc. = absorption greater (or less) in the direction of X than in the direction of Y (or Z), etc.

Y = the vibration direction of the intermediate ray = $\mathfrak{b}$ of German writers.

Z = the vibration direction of the slowest ray = $\mathfrak{c}$ of German writers.

Other abbreviations, used less commonly, are defined where used.

$\wedge$ = angle; for example, $Z \wedge c$ = the angle between Z and c.

$>$ = greater than.

$<$ = less than.

100, 010, 001, 110, etc. = Miller symbols of crystal faces and forms.

$\perp$ = normal to.

$\|$ = parallel; this is often omitted, as in the statement: "the optic plane is 010"; or it is replaced by "=," as in "X = a."

OPTICAL MINERALOGY

PART II

INTRODUCTION

DRAWINGS, PROJECTIONS AND DIAGRAMS

IT may be assumed that ordinary drawings of crystals in clinographic or orthographic projection or true perspective will be understood by those who use this book, since they are simple, and fully explained in nearly any textbook of mineralogy.

Certain other types of projection need some explanation, because they do not give a picture of the actual crystal, but are very useful since they present a graphic expression of symmetry and of all the angular relations of the crystal much more clearly and exactly than any picture.

In spherical projection the crystal is supposed to have its center at the center of an enclosing sphere, as in Fig. 1. From the common center a line is drawn normal to each crystal face and this line is continued until it intersects the enclosing sphere. The point of intersection is known as the pole of the given face. The poles of all faces in one zone (that is parallel to one line in the crystal) are in one great circle in the sphere. Conversely, all faces whose poles are in one great circle belong to one zone in the crystal. A face whose pole falls at the intersection of two or more great circles belongs to two or more independent zones in the crystal. The angular relations between the faces are retained exactly on the sphere; the angles on the sphere, being the angles between normals to the faces, are the supplements of the actual interior angles between the faces of the crystals. These angles between the normals to the faces are the "normal interfacial angles" commonly recorded in all the literature on the subject.

It is customary to place the crystal so that the vertical axis is normal to the equatorial plane of the sphere; then an orthorhombic crystal has the pole of the face 001 at the north pole of the sphere and any crystal has the poles of all faces of the prism zone (100, 110, 010, 110, etc.) on the equatorial circle. Since crystals are commonly alike at the two ends of the vertical axis, it is unnecessary to use more than half the sphere; the upper or northern hemisphere is commonly employed.

The chief disadvantage of spherical projection is that the surface of projection is curved and therefore can be shown in a plane figure only pictorially or by means of another projection. To use the spherical projection directly an actual spherical surface is needed; a hemisphere, such as that of Nikitin[1] (Fig. 2), with movable graduated circles, serves the purpose well. Two methods are in common use to convert a spherical projection into a plane figure; one is known as the stereographic projection and the other as the gnomonic projection.

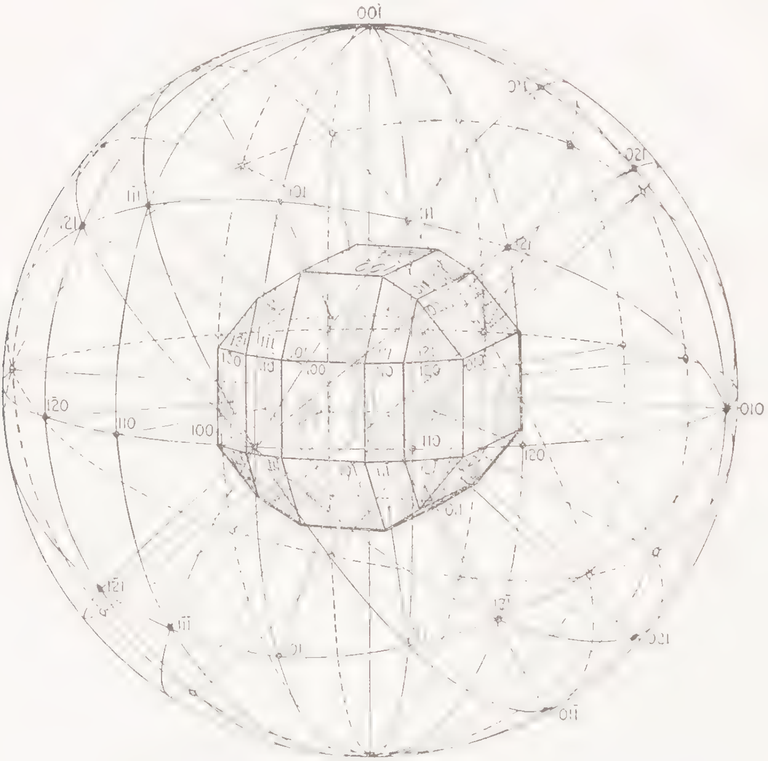

Fig. 1.—Derivation of a spherical projection.

The stereographic projection may be derived from the spherical projection by projecting each pole on the upper hemisphere onto the

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[1] *Zeit. Kryst.*, XLVIII, 1910, p. 379.

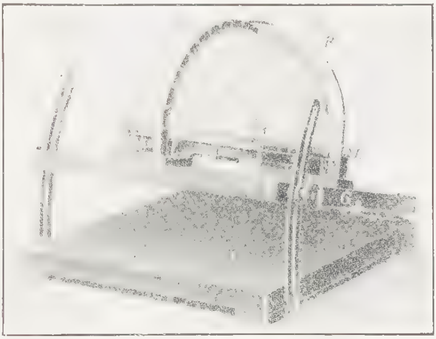

FIG. 2.—Hemisphere of Nikitin.

equatorial plane of the sphere by means of a straight line from the pole of the face to the south pole of the sphere, as shown in Fig. 3. In the figure it is evident that lines (of projection) are drawn from each pole on the upper hemisphere to the south pole of the sphere; the points where these lines intersect the equatorial plane (which is the plane of projection) are the poles of the respective faces in a stereographic projection. The stereographic projection of the crystal of Fig. 1, derived from the spherical projection as shown in Fig. 3,

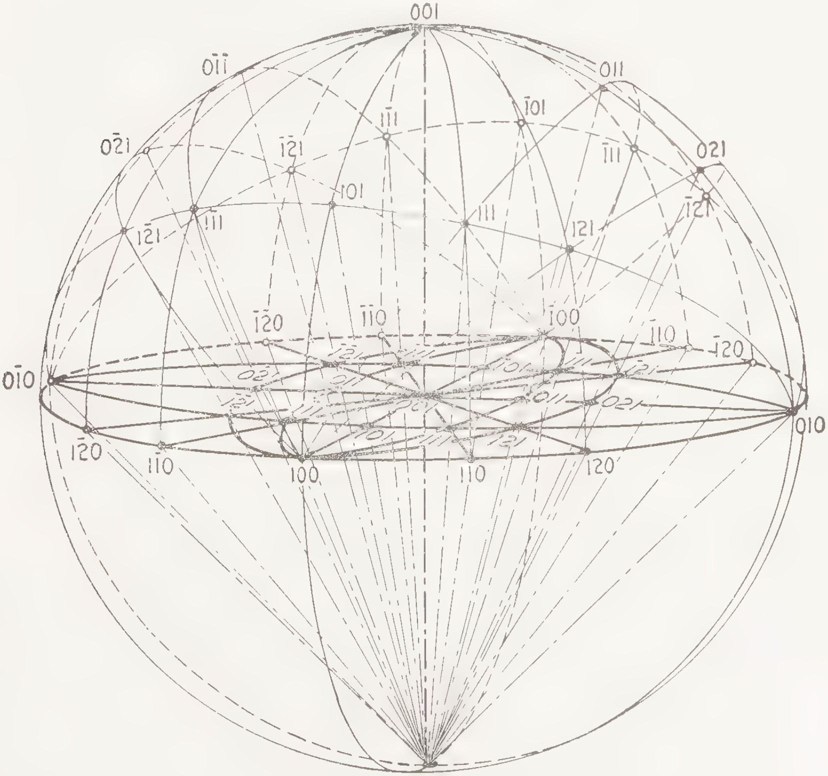

FIG. 3.—Derivation of a stereographic projection.

is represented in full view in Fig. 4. It is important to note that all great circles of the spherical projection appear as arcs of true circles in the stereographic projection, the only apparent exception being that all great circles passing through both the north and south poles of the spherical projection appear as straight lines in the stereographic projection (but such lines are arcs of circles of infinite radius).

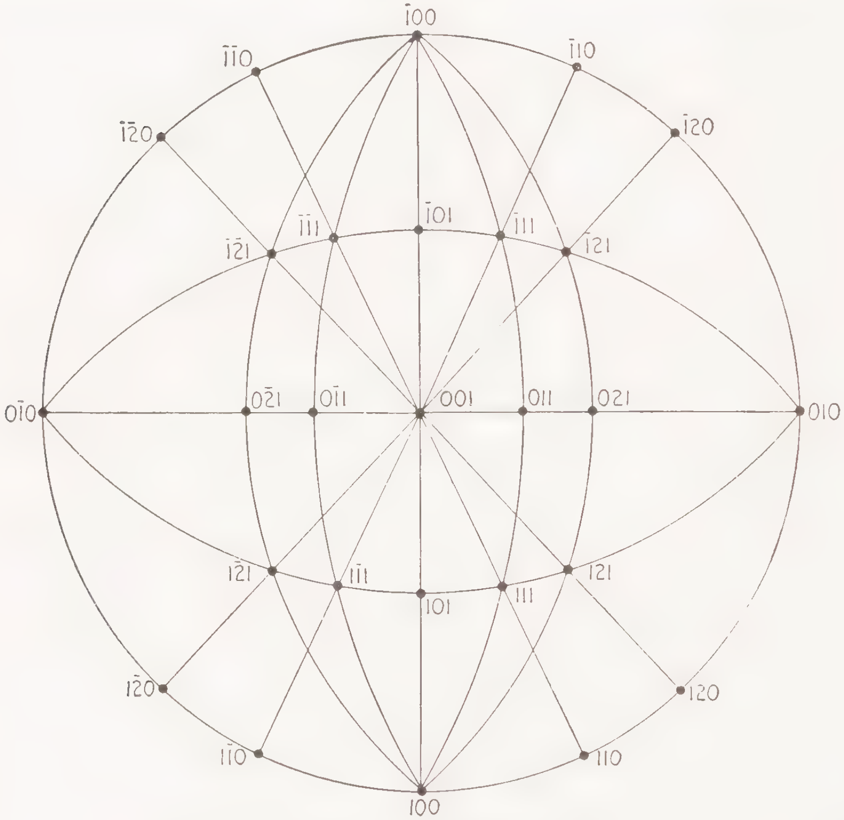

Fig. 4.—Example of a stereographic projection.

The poles of all faces which are parallel to the vertical axis of the crystal are on the equator of the spherical projection and remain at the same points on the boundary circle (equator) of the stereographic projection. The pole of a face normal to the vertical axis of the crystal is at the north pole of the spherical projection and at the center of the stereographic projection. Penfield[2] devised convenient protractors for plotting and for measuring angles in stereographic projections of definite radius.

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[2] *Am. Jour. Sci.*, CLXI, 1901, p. 10.

The stereographic projection is well adapted to show all the optic properties of a single crystal, as illustrated in its use to show the properties of albite, etc., by Michel Lévy. It can be used to show variations in the position of optic elements in an isomorphous series, but is not well adapted to show variations in refringence, birefringence, optic angle, or extinction angles in such a series.

The gnomonic projection may be derived from the spherical projection by taking a plane tangent to the sphere at the north pole as the plane of projection and projecting from the center of the sphere the pole of each face upon this plane, as in Fig. 5. In gnomonic projections all great circles of the spherical projection become straight lines. Therefore the poles of all faces in any one zone lie in a straight line in a gnomonic projection. The pole of a face normal to the vertical axis of the crystal is at the center of the gnomonic projection. The poles of all the vertical faces lie at infinite distances from the center; such faces may be indicated by the use of radial lines or arrows indicating the directions in which their poles lie. Crystal faces steeply inclined to the horizontal are often indicated in the same way to avoid making too large a drawing. In gnomonic projections the distance of the pole of a given face from the center is equal to the tangent of the normal angle between the base and the given face, considering the distance of the plane of projection from the center of the sphere to be unity. The distance of projection is often conveniently taken

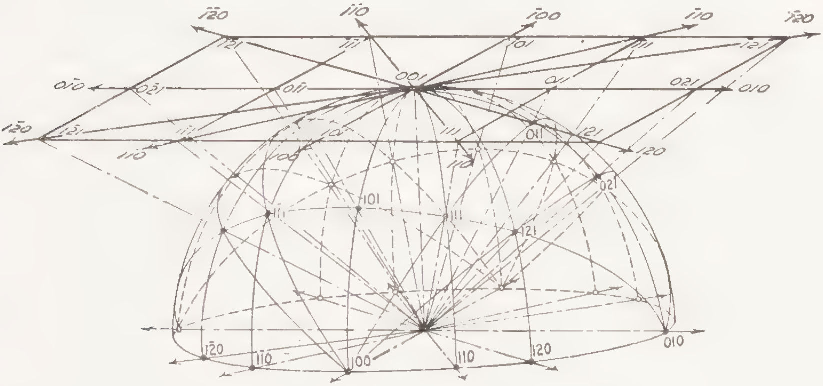


Fig. 5.—Derivation of a gnomonic projection.

as 5 cm.; then a face such as 011 in an isometric crystal has its pole at 5 cm. from the center.

Spherical, stereographic, and gnomonic projections are used chiefly in studying single crystals; other types of drawings are more useful to illustrate variations in properties in an isomorphous series or system.

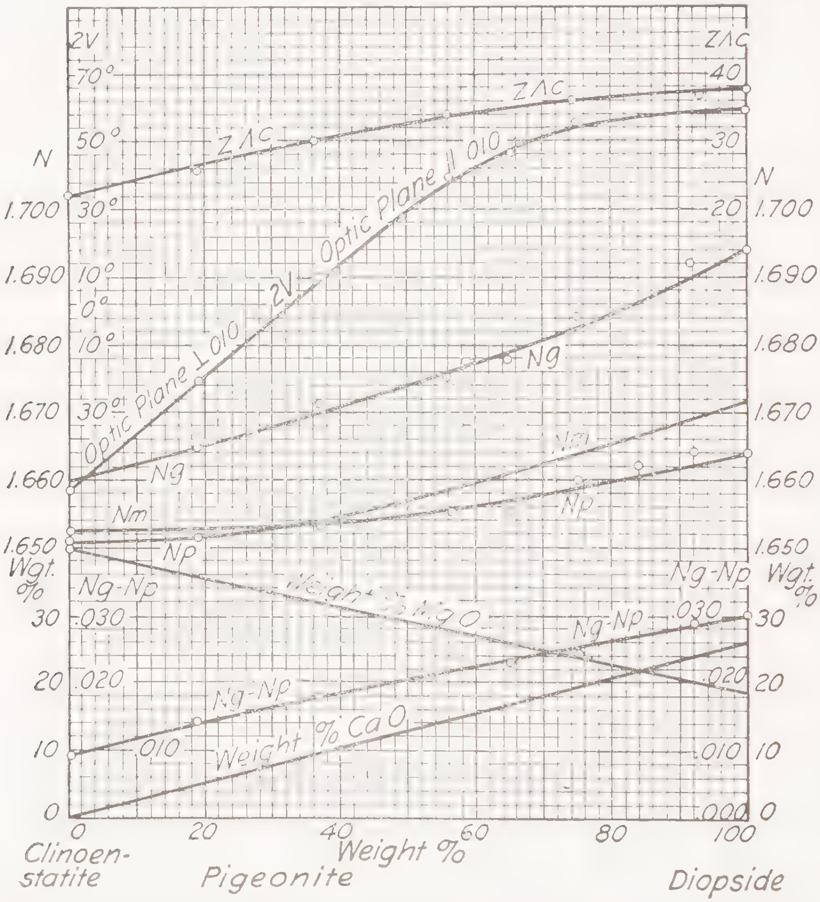


Fig. 6.—Variations in optic properties with variation in composition in a binary series.

The ordinary system of two coordinates is commonly used to show variations in properties in an isomorphous binary series, that is, in a case involving only two molecules, such as plagioclase. One coordinate—commonly the horizontal—is taken to represent variation in composition from one pure molecule at one end of the line to the other pure molecule at the other end of the line. By dividing this line into ten equal parts, each division point represents simple decimal proportions of the two molecules. Then the other coordinate can be used to represent any property of the substance, such as the mean index of refraction, the specific gravity, the extinction angle, or the fusing point. By placing one or more suitable scales on this coordinate the numerical value of the index or other property can be read directly from the diagram for any composition shown, and the variations of the properties with variations in composition through the series can be seen conveniently. Figure 6 furnishes an illustration of such a diagram.

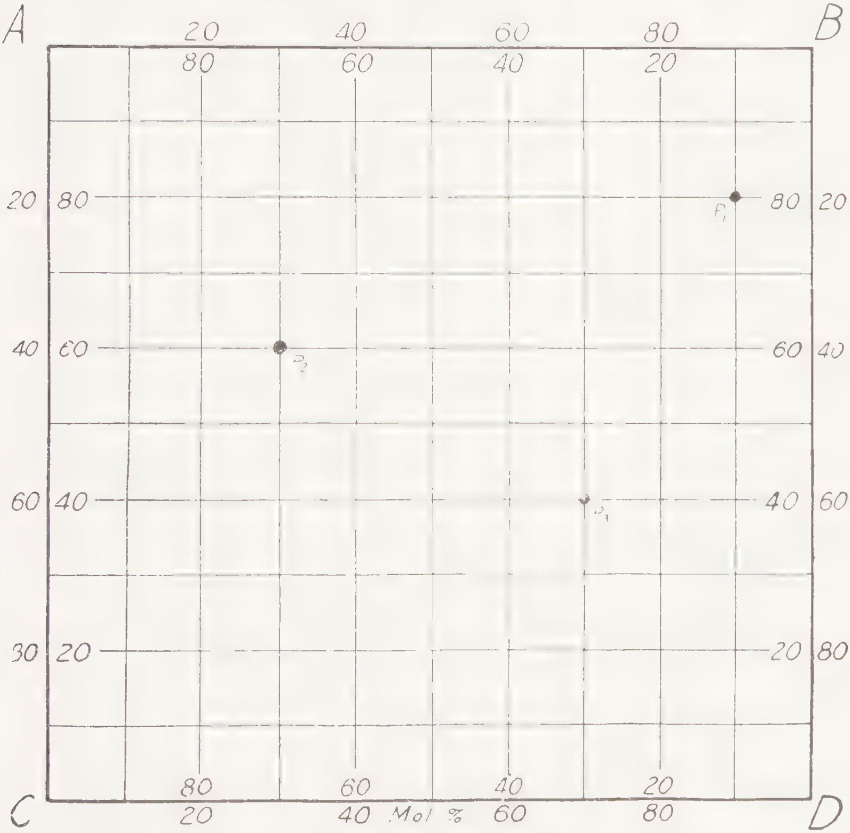


FIG. 7.—Diagram for two independent variables leading to four molecules.

In some cases there are two kinds of variations in composition in an isomorphous system which are quite independent. One of the simplest cases of this kind is found in the spinel group in which $MgAl_2O_4$

may vary in one way to $FeAl_2O_4$, and, wholly independent of this variation, there may be another variation from $MgAl_2O_4$ to $MgCr_2O_4$. In such cases each variation in composition should be plotted as one of the usual coordinates, as in Fig. 7, in which $MgAl_2O_4$ may be assumed to be at A; then $FeAl_2O_4$ may be at B, and $MgCr_2O_4$ at C. It is evident that if both these variations are assumed to occur the result will be $FeCr_2O_4$, and this molecule should be used to complete the square, as at D. Now, if the opposite sides of the square are divided in tenths and corresponding divisions are connected by straight lines, the whole area of the square may be divided so that the percentage composition may be easily read at any point. For example, the point P_1 represents 90 per cent of the iron molecules (B and D) and 10 per cent of the magnesium molecules (A and C); it also represents 80 per cent of the aluminum molecules (A and B) and 20 per cent of the chromium molecules (C and D); therefore it represents 90 per cent of 80 per cent or 72 per cent of B, 10 per cent

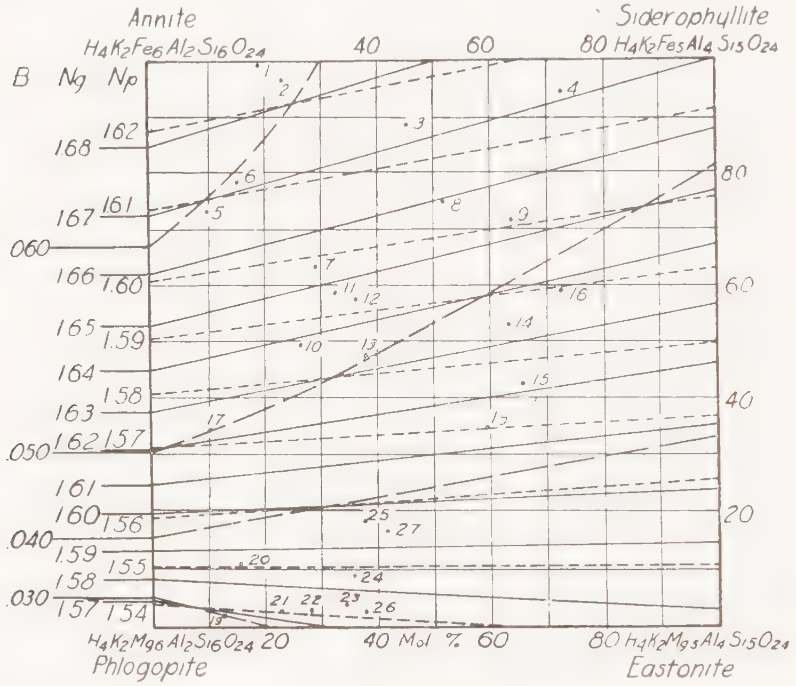


FIG. 8.—Variations in optic properties with variations in composition in a system of four molecules.

of 80 per cent or 8 per cent of A, 90 per cent of 20 per cent or 18 per cent of D, and 10 per cent of 20 per cent or 2 per cent of C. Similarly, P_2 represents 42 per cent of A, 18 per cent of B, 28 per cent of C, and 12 per cent of D. Variations in physical properties are not shown as easily on such a diagram as on one for a binary system, but they can be shown, either as lines of equal properties, like contours, or as measured above the plane of the square in a solid model.

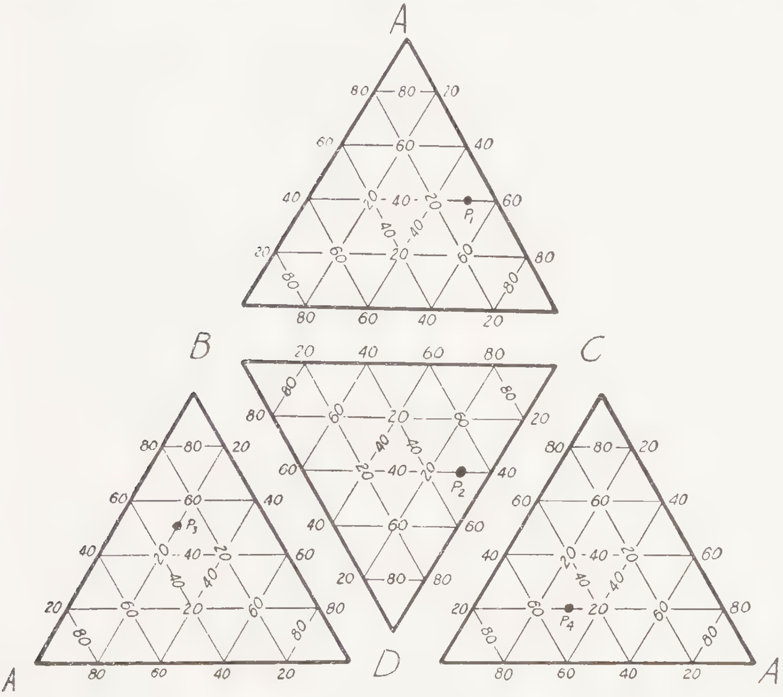


FIG. 9.—Diagram for three (and four) independent variables.

It is necessary to use the method of "contours" in plane figures. An illustration may be found in Fig. 8.

In some cases a mineral molecule varies in composition only as to one component, but more than one other element may take the place of this component. A simple illustration of such a case is furnished by $MgCO_3$ which may vary to $FeCO_3$ or to $MnCO_3$ or to mix-crystals containing all three of these molecules. In this instance there must always be exactly 100(Mg+Fe+Mn) atoms for each 100 CO_3 groups. That is, the sum of Mg+Fe+Mn is a constant in all parts of the system, and this constant may be taken as 100, for convenience.

Such a system may be represented on a triangle, the three corners of which represent the three pure molecules, as in any one of the triangles of Fig. 9. Then by dividing the sides of the triangle into tenths and connecting these points by straight lines, as in the figure, the whole triangle is divided so that the composition represented at any point may be read off very easily. For example, the point P_1 represents 40 per cent of A, 10 per cent of B, and 50 per cent of C; the point P_3 represents 50 per cent of B, 30 per cent of D, and 20 per cent of E. Of course, the physical properties can be shown on such a triangle just as on a square, either by distances measured above the plane of the triangle in a solid model, or by contours. They are shown by "contours" in Fig. 10 for the tephroite-forsterite-fayalite system. The properties of two of the three binary series of this system are only approximately known, and data in the ternary field are very

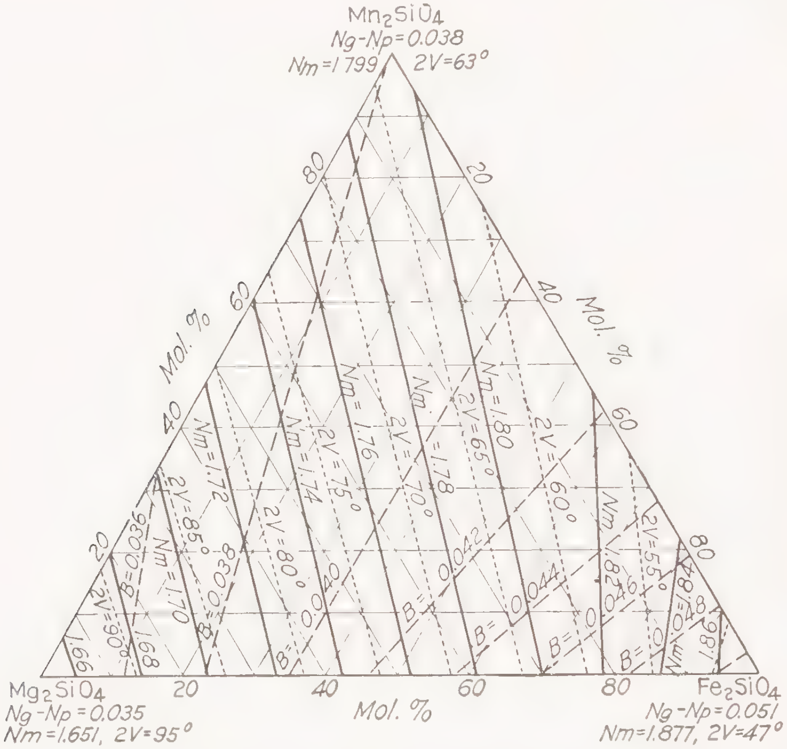


FIG. 10.—Variations in optic properties with variations in composition in a system of three independent variables.

scanty, so the "contours" are all drawn as straight lines; in general, such lines are straight or only moderately curved.

In some cases variations in one component of a molecule may lead to three other molecules. For example, chalcanthite ($CuSO_4 \cdot 5H_2O$) may vary to siderotilite ($FeSO_4 \cdot 5H_2O$) or to cobalt-chalcanthite ($CoSO_4 \cdot 5H_2O$) or to manganese-chalcanthite[3] ($MnSO_4 \cdot 5H_2O$). In this case the constant which may be considered 100 is Cu + Fe + Co + Mn. A tetrahedron is required to illustrate all possible mixtures of the four molecules, but, fortunately, in minerals, one of the four components is nearly always so inferior in amount that the point representing the composition is very near, and may be considered to be on, one side of the tetrahedron. The four sides of the tetrahedron may be drawn, therefore, as in Fig. 8, and practically all the actual cases can be represented on one of the four triangles. The triangle BCD may be considered the base of the tetrahedron, and the other triangles the three sides having the common apex, A.

[3] Continuity in all parts of this system has not been demonstrated.

DESCRIPTIONS OF MINERALS

WITH SPECIAL REFERENCE TO THEIR OPTIC AND MICROSCOPIC CHARACTERS

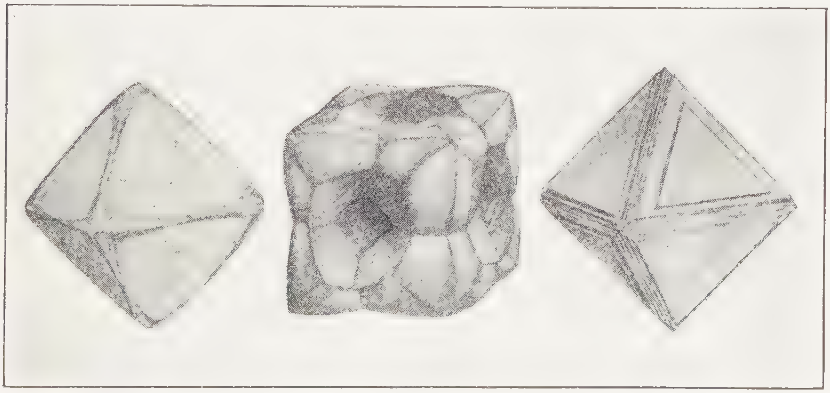
I. ELEMENTS

So far as the native elements are opaque, only a few of the more important are included.

1. NON-METALLIC ELEMENTS

DIAMOND ISOMETRIC C

PHYS. CHAR.—Crystals commonly octahedrons, dodecahedrons; also cubes, tetrahedrons, and modified forms; faces usually curved, and often striated. Twinning on 111 common, both contact and penetration types; also on 001. Perfect 111 cleavage. H. = 10. G. = 3.2–3.52. Infusible. Insoluble in acids and alkalies. Diamond has the lowest known compressibility.



FIGS. 11–13.—Natural crystals of diamond. (After Goldschmidt: *Atl. Kryst.*, III, 1916, and Fersmann and Goldschmidt: *Diamant*, 1911).

OPT. PROP.—Usually isotropic. Refringence extremely high. Sometimes shows abnormal birefringence, which may be in regular areas or localized about inclusions; rarely distinctly uniaxial. Dispersion very strong.

$$N = 2.4135 \text{ Li}, \quad 2.4195 \text{ Na}, \quad 2.4278 \text{ Tl}.$$

Colorless, white, yellow, orange, red, green, blue, brown, black. In thin section transparent to nearly opaque, but not pleochroic.

INVER.—Inverts to another form[1] at about 1885° C.

INCL.—Inclusions are gaseous or solid; often carbonaceous and abundant, thus giving color.

OCCUR.—In alluvial deposits associated with heavy minerals; also in quartz conglomerate, in itacolumite, and in a peculiar peridotite called kimberlite. Also found in glacial drift. Also known in a few meteorites.

DIAG.—The hardness, adamantine luster, and insolubility are quite distinctive. Rarely found in thin sections, even of diamondiferous rocks, because not polished by ordinary processes.

GRAPHITE HEXAGONAL $c = 1.386$ C

PHYS. CHAR.—Crystals rounded hexagonal lamellæ; usually found in concentric foliated masses. Perfect basal cleavage; the laminæ are flexible and not elastic. H. = 1–2. Greasy feel. G. = 2.25. Infusible; deflagrates with KNO_3. Insoluble.

OPT. PROP.—Opaque in thin sections, but translucent to greenish-gray light in flakes made on a streak plate. Uniaxial negative [2] with N between 1.93 and 2.07. Birefringence not strong. Color and streak black.

OCCUR.—Graphite is found in small amount in many igneous rocks; also in greater quantity in some schists and gneisses. It is also found in contact rocks, in beds of coal that have been subject to metamorphism, and in meteorites.

ALTER.—Changes to graphitic acid (when treated with HNO_3 and $KClO_3$) which has nearly the same optic properties, and is pleochroic with O = dark green and E = almost colorless.

DIAG.—Graphite deflagrates in a platinum spoon with niter, producing potassium carbonate. Molybdenite resembles graphite in external characters, but is fusible, giving sulphur coatings; it is attacked by nitric acid, it does not deflagrate, and it has a streak on smooth porcelain which is slightly greenish instead of black.

SULPHUR ORTHORHOMBIC $a : b : c = 0.813 : 1 : 1.903$ S

PHYS. CHAR.—Crystals usually pyramidal; also thick tabular, or modified. Twinning on 101, sometimes interpenetrated; also on 110 or 011, rare. Imperfect 001, 110, and 111 cleavages. H. = 2. G. = 2.05–2.09. Melts at 108° C. and burns at 270° C. Insoluble in acids; soluble in CS_2.

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[1] *Bull Soc. Fr. Min.*, XLVII, 1924, p. 94.

[2] P. Gaubert: *Comp. Rend.*, CLXXVII, 1923, p. 1123.

Opt. Prop.—The optic plane is 010; the acute bisectrix Z is normal to 001. $(+)2V = 68°\ 58'$ Na, $\rho < v$ weak. $N_g = 2.245$, $N_m = 2.038$, $N_p = 1.958$, $N_g - N_p = 0.287$.

Color yellow; rarely brownish, greenish, grayish.

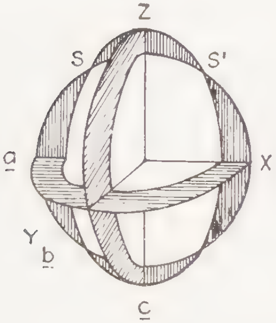

Fig. 14.—Wave-fronts in axial planes in sulphur, differences of velocities being exaggerated.

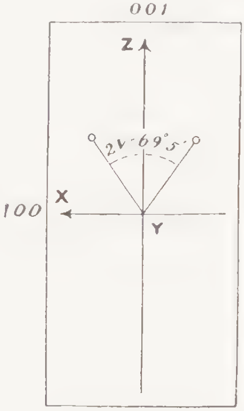

Fig. 15.—Diagram of optic orientation of sulphur.

Isotropic mixtures of fused S and Se are useful immersion media. Indices are given below.

%S	100	90	80	70	60	50	40	30	20	10	0
%Se	0	10	20	30	40	50	60	70	80	90	100
N(Li)	1.978	2.00	2.03	2.07	2.11	2.16	2.22	2.30	2.40	2.53	2.716
N(Na)	1.998	2.025	2.06	2.10	2.15	2.20	2.27	2.37	2.49	2.67	2.92
N(Tl)	2.018	2.05	2.09	2.13	2.19	2.25	2.32	2.43			

Inver.—Orthorhombic sulphur inverts to a monoclinic form called *β-sulphur*, or *sulfurite*, at 98° C. Other crystal forms are known.

Alter. Sulphur oxidizes slowly to sulphurous and sulphuric acids which yield sulphates.

Occur.—Especially in deposits of gypsum; also abundant about volcanoes. Less abundant in coal deposits, veins, etc., as a result of reduction of sulphides or sulphates. Deposited by some hot springs.

2. METALLIC ELEMENTS

COPPER Isometric Cu

Phys. Char.—Crystals often modified cubes, often in complex groups; no cleavage. Highly malleable. H. = 2.5–3. G. = 8.8–8.9. Fuses at 780° C. Soluble in HNO_3.

Opt. Prop.—Color copper-red; luster metallic. Opaque in thin section. N = 0.62 Na, 0.89 Tl. In vertical reflected light pink.

ALTER.—Oxidizes to cuprite, or changes to malachite or azurite.

OCCUR.—In veins in all kinds of rocks, and in amygdaloidal cavities in basaltic rocks associated with calcite, zeolites, etc.; also found rarely in sediments, especially sandstones.

Silver (Ag) is also isometric. Crystals like copper. No cleavage. H. = 2.5–3. G. = 10.5. Easily fusible. Soluble in HNO_3. Color and streak silver white. Luster metallic. Opaque. N = 0.18 Na. In vertical reflected light creamy white. May produce slight rotation of the plane of polarization of reflected light. Found in veins in igneous and metamorphic rocks. Very rarely found disseminated in igneous rocks. Often associated with native copper, galena, chalcocite, cerargyrite, etc.

Gold (Au) in nature usually contains 1–10 per cent Ag and often a little Cu and Fe. It is isometric, crystals being octahedrons, dodecahedrons or modified. Twinning on 111. Cleavage none. H. = 2.5–3. G. = 15.6 19.3. F. = easy. Soluble in aqua regia. N = 0.41 Na, 0.53 Tl. Color and streak gold yellow grading to silver white with increase of silver. The presence of copper darkens the color. Opaque in thin section, but may be beaten into films which transmit a greenish light. In vertical reflected light yellow. Found especially in quartz veins in igneous and metamorphic rocks; also in calcite veins, etc. Also in placer deposits. Associated especially with pyrite, less commonly with chalcopyrite, galena, sphalerite, arsenopyrite, etc.

IRON ISOMETRIC Fe

PHYS. CHAR.—Usually massive; rarely in cubic or octahedral crystals with perfect cubic cleavage. Strongly magnetic. H. = 4.5–5. G. = 7.3–7.8. Fusible at about 1500° C. Soluble to a yellow solution in HCl.

OPT. PROP.—N = 2.27. Opaque; color iron black to steel gray. In thin section color and luster only observed by reflected light.

ALTER.—Alters rapidly to limonite when exposed to the air.

OCCUR.—In some igneous rocks very sparingly. Large masses found in Greenland in basalt. Iron is found in meteorites, in some cases making up the entire mass, in other cases a large portion, and in still other cases a small part of the whole. Meteoric iron always contains nickel (5 per cent to 10 per cent commonly) and a little cobalt, the amount being greater than in native iron. Further, it shows Widmanstätten figures when etched by dilute nitric acid upon a smooth surface.

II. SULPHIDES, ETC.

Sulphides, selenides, tellurides, arsenides, antimonides, oxysulphides and sulphosalts are included in this division. Carbides are also included, as well as the few natural hydrocarbons, since the latter are regarded as more closely related to carbides than to salts of organic acids. All transparent and translucent minerals are included if their optic properties are known, but only the more important opaque minerals.

1. CARBIDES

MOISSANITE TRIGONAL $c = 1.226$ SiC

Phys. Char.—Crystals thin basal plates with rare twinning on $10\bar{1}1$ and poor basal cleavage. H. = 9.5. G. = 3.2. Infusible, but dissociates at about 3400° C. Insoluble even in HF.

Opt. Prop.—Uniaxial positive with extremely high refringence, strong birefringence and very strong dispersion, as follows:[1]

$\lambda = 755\mu\mu$	671	589 (Na)	535 (Tl)	486	422	Dispersion (422–755)
$N_e = 2.654$	2.673	2.697	2.721	2.749	2.808	0.154
$N_o = 2.616$	2.633	2.654	2.675	2.700	2.753	0.137
$N_e - N_o = 0.038$	0.040	0.043	0.046	0.049	0.055	0.017

Colorless when perfectly pure, but usually colored green, blue, red, black by small amounts of iron, alumina, carbon, etc., present as impurities. Bluish crystals are pleochroic with X>Z. Further, surface films of silica, commonly present, produce iridescent colors.

Occur.—Found by Moissan in the Canon Diablo meteorite. It is an important artificial product of the electric furnace known commercially as *carborundum.*

Diag.—Readily recognized by extreme hardness, extreme refringence and extreme dispersion.

2. NATURAL HYDROCARBONS

Paraffin (C_nH_{2n+2}, with $n=16$ or more) is related to "liquid crystals." H. = 1. G. = 0.9. F. = 44° C., 56°, etc. Soluble in ether; insoluble in acid. Burns readily. Uniaxial positive with $N_o = 1.478$ to 1.503, $N_e = 1.525$ to 1.545, $N_e - N_o = 0.047$ to 0.042 (Camerer,[2] for paraffin with F. = 40° C. to 80°), $N_o = 1.49$, $N_e = 1.52$, $N_e - N_o = 0.03$ (Gaubert,[3] for paraffin with F. = 44° C.); $N_o = 1.502$, $N_e = 1.550$, $N_e - N_o = 0.048$

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[1] H. E. Merwin: *Jour. Wash. Acad. Sci.*, VII, 1917, p. 445.

[2] *Ann. Phys.*, LIV, 1895, p. 84.

[3] *Bull. Soc. Fr. Min.*, XXXIII, 1910, p. 335.

(Larsen [4]). Color white. When crushed under a cover glass all fragments become oriented normal to optic axis. Found in cavities in basalt. Very rare.

Ozocerite is a kind of paraffin. Uniaxial positive with $N_o = 1.515$, $N_e = 1.54$, $N_e - N_o = 0.025$. Color white. When crushed under a cover glass all fragments become oriented normal to optic axis. Also may be biaxial of small optic angle.[5] Found in seams in coal or bituminous shale and in veins in Utah. Rare.

Hatchettite is a kind of paraffin in thin plates or massive. H. = 1. G. = 0.96. F. = 80° C. Soluble in oils, but not in acids. Burns readily. Nearly uniaxial and positive with $N_o = 1.480$, $N_e = 1.502$, $N_e - N_o = 0.022$ (Gaubert [6]); also biaxial and probably orthorhombic with (+) $2E = 10 \pm$, $\rho < v$, weak to distinct (DesCloizeaux [7]); (+) $2V = 0° - 33°$, $\rho < v$, strong, $N_g = 1.588$, $N_m = 1.523$, $N_p = 1.518$, $N_g - N_p = 0.070$ (Morozevicz,[8] on hatchettite with F. = 79° C. and formula: $C_{38}H_{78}$, having one good cleavage normal to Z). When crushed under a cover glass all fragments become oriented normal to Z. On recrystallization the fibers have negative elongation.

Curtisite [9] ($C_{60}H_{40}O$?) is probably orthorhombic with perfect 001 and poor 100 cleavages. H. > 2. G. = 1.21. F. = 350° C. Soluble in hot benzol. The optic plane is 010; $Z = c$. (+) $2V = 83\frac{1}{2}°$, $\rho > v$ weak. $N_g = 2.07$, $N_m = 1.734$, $N_p = 1.557$, $N_g - N_p = 0.513$. Color greenish yellow with X = pale yellow to colorless, Y = yellow, Z = yellow and $X < Y < Z$. Found about hot springs in California.

Hoelite [10] (*anthraquinone*, $C_{14}H_8O_2$) is orthorhombic with $a : b : c = 0.80 : 1 : 0.16$. Crystals prismatic with imperfect 100 and 001 cleavages. G. = 1.43. Optic plane is 100; $X = c$. Optic sign unknown. 2V = small, $N_m = 1.75 \pm$, $N_p = 1.57$, $N_g - N_p = 0.3 \pm$. Colorless. Found on the walls of holes through which vapors from a burning coal seam escaped in Spitzbergen. Very rare.

Fichtelite ($C_{18}H_{32}$) is monoclinic with $a : b : c = 1.428 : 1 : 1.749$, $\beta = 53° \pm$. Crystals basal tablets or elongated parallel to b. Perfect 001 and distinct $\bar{1}01$ cleavages. Twinning on 001. H. = 1. F. = 46° C. Soluble in ether. Optic plane is 010; $Z \wedge c$ [11] $= +13°$. (+) $2V = 87° 20'$, $N_g = 1.60$ (calc.), $N_m = 1.578$, $N_p = 1.54$, $N_g - N_p = 0.060 \pm$. Color white. Found as scales in wood and peat. Rare.

Hartite [12] ($C_{18}H_{30}$) is triclinic asymmetric with $a : b : c = 1.824 : 1 : 0.657$, $\alpha = 100° 26'$, $\beta = 93° 44'$, $\gamma = 80° 31'$. Crystals 100 tablets with G. = 1.04. F. = 74° C. Soluble in alcohol. Acute bisectrix Z is oblique to 100; optic plane nearly normal to 100 making an angle of 3° with $\bar{1}11$ in 100. (+)$2E = 154°$. Indices unknown. Found on lignite.

3. SULPHIDES, ETC., OF MONOVALENT ELEMENTS

CHALCOCITE Orth. $a : b : c = 0.582 : 1 : 0.970$ Cu_2S

Comp.—May contain CuS in crystal solution; this lowers the specific gravity.

Phys. Char.—Crystals may be hexagonal in aspect; 001 and 100 cleavages. H. = 2.5–3. G. = 5.785 (pure). Fuses at 1130° C. Soluble in HNO_3.

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[4] *U. S. Geol. Surv. Bull.*, 679, 1921, p. 186.

[5] G. Césaro: *Ann Soc. Geol. Belg.*, XVIII, 1891, p. lxxxviii.

[6] *Bull. Soc. Fr. Min.*, XXXIII, 1910, p. 335.

[7] *Man. Minéral.*, II, 1874, p. 38.

[8] *Bull. Acad. Sci. Cracovie*, 1908, p. 1067.

[9] F. E. Wright and E. T. Allen: *Am. Mineral*, XI, 1926, p. 67.

[10] I. Oftsdal: *Min. Abst.*, II, 1923, p. 10; *Tables Ann. Intern. Const.*, V, 1925.

[11] *Abh. böhm. Akad.*, 1907, No. 13. *Neues Jahrb. Mineral.*, 1908, II, p. 40. *Zeit. Kryst.*, L, 1911, p. 126.

[12] F. Machatschki: *Zeit. Kryst.*, LX, 1924, p. 130.

Opt. Prop.—Opaque. Color blackish lead gray. In inclined reflected light has metallic luster and dark lead gray color. In vertical reflected light bluish white. After etching produces a noticeable rotation of the plane of polarization of reflected light.

Inver.—Changes to an isometric form (G. = 5.65) at 91° C.; the change is reversible. The base of an orthorhombic crystal which has inverted, corresponds to a dodecahedral face of an isometric crystal. More than 8 per cent of CuS in crystal solution prevents inversion. Pure chalcocite crystals constitute a useful "geologic thermometer," since orthorhombic forms signify temperatures below about 91° C.

Alter.—Tarnish not uncommon; may alter to covellite or chalcopyrite or bornite.

Occur.—Chiefly in veins with chalcopyrite, bornite, enargite, etc. Also formed by action of hot spring water on coins.

Acanthite (Ag_2S) is orthorhombic with $a : b : c = 0.689 : 1 : 0.994$. Crystals prismatic with no distinct cleavage. H. = 2.5. G. = 7.2–7.3. F. = 1.5. Soluble in HNO_3. Opaque. Color and streak blackish lead gray; in vertical reflected light grayish white. Changes (reversibly) to an isometric form [13] (*argentite*) at 179° C. Found chiefly in veins often associated with galena; also with copper or gold ores.

4. MONOSULPHIDES, ETC., OF DIVALENT ELEMENTS

GALENITE Isometric PbS

Phys. Char.—Crystals cubes, octahedrons, etc., with perfect cubic cleavage. H. = 2.5. G. = 7.5. F. = 2 (1100° C. in N). Decomposed by H_2SO_4.

Opt. Prop.—Opaque. Color and streak lead gray. N = 3.91. Polishes readily; upon etching the portion dissolved is often limited by cubic planes. In vertical reflected light galena white.

Alter.—Alters rather easily to cerussite; also to anglesite, pyromorphite, mimetite, wulfenite, linarite, miniumite.

Occur.—Galena is one of the most widely distributed of the metallic sulphides. It is found in quartz veins in rocks of all kinds, often associated with ores of zinc, copper or silver; it is abundant in some calcite (or dolomite) veins, and in disseminated deposits in sedimentary rocks often associated with sphalerite, pyrite, marcasite, and various carbonates. It occurs less commonly as a product of contact metamorphism; as a result of the action of hot springs upon coins; and as a furnace product.

SPHALERITE Isometric ZnS

Phys. Char.—Crystals tetrahedral, often complex. Twinning on 111. Perfect dodecahedral cleavage. H. = 3.5–4. G. = 4.09. Sublimes in N at 1178° C. Soluble in HCl.

Opt. Prop.—Isotropic; rarely anisotropic probably on account of strain since anisotropic areas are easily produced by pressure with a pin point on a section. Refringence extremely high and varying with tenor of iron as follows:

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[13] R. C. Emmons and C. H. Stockwell: *Am. Mineral.*, XI, 1926, p. 326.

% FeS	N(Li)	N(Na)	G.	Inverts at
0.2	2.340	2.368	4.09	1020° C.
8.6	2.36	2.40	4.02	955° C.
17.0	2.38	2.43	3.98	919° C.
28.2	2.395	2.47	3.94	880° C.

" Amorphous " ZnS has $N = 2.18$ to 2.25.

Color brown, black, yellow; rarely green, red, colorless. In thin section may show zonal distribution of color. In vertical reflected light gray.

Inver.—Pure sphalerite inverts to wurtzite at 1020° C.; 28 per cent FeS lowers this temperature to 880° C.; CdS raises it.

Alter.—Rather easily changed to goslarite, smithsonite, calamine, and sometimes limonite.

Occur.—Common in veins, often associated with galenite; also with chalcopyrite, tetrahedrite, calcite, siderite, quartz, fluorite, barite.

Alabandite (MnS) is also tetrahedral, in cubes, etc.; usually granular massive; perfect cubic cleavage. H. = 3.5–4. G. = 4.0. F. = 3. Soluble in HCl. Translucent and isotropic with extreme refringence, N = 2.70 Li. Color iron-black with brown tarnish; streak green. In vertical reflected light grayish white. Found chiefly in metalliferous veins. Formed in steel furnaces.

Covellite (CuS) is hexagonal with $c = 1.1466$; crystals horizontally striated with perfect basal cleavage; flexible in thin laminæ. H. = 1.5–2. G. = 4.68. Before the blowpipe burns, giving off SO_2, and fuses at 2.5. Extremely thin plates translucent and pleochroic in light-green tints. Uniaxial positive[14] with $N_o < 1.0$ Li, $= 1.45$ Na. $= 1.81$ Tl. $N_e - N_o$ = weak. Usually opaque. The deep indigo blue color in reflected light is distinctive, together with a submetallic, somewhat resinous luster. Blue in vertical reflected light. Produces marked rotation of the plane of polarization of reflected light. Found associated with other copper ores, as chalcocite and chalcopyrite. Sometimes derived from the alteration of chalcocite. Rare.

Niccolite (NiAs) is hexagonal with $c = 0.819$; usually massive. H. = 5–5.5. G. = 7.33–7.67. F. = 2. Soluble in aqua regia. Opaque. Color pale copper red with dark-gray tarnish. In vertical reflected light creamy pink. In some cases produces a noticeable rotation of the plane of polarization of reflected light. Found in veins with cobalt, silver and copper ores. Rare.

WURTZITE Hexagonal $c = 0.8175$ ZnS

Phys. Char.—Crystals hemimorphic, short prismatic or pyramidal in aspect. Prismatic cleavage easy. H. = 3.5–4. G. = 3.98–4.08. Sublimes in N at 1185° C.; reforms on cooling. Soluble in HCl.

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[14] H. E. Merwin: *Econ. Geol.*, X, 1915, p. 530.

Opt. Prop.—Uniaxial positive with $N_o = 2.356$ Na, $N_e = 2.378$, $N_e - N_o = 0.022$. With 28 per cent FeS the indices are about $N_o = 2.46$, $N_e = 2.48$. Commonly fibrous to lamellar parallel to 0001 with negative elongation. Color yellow to black like sphalerite; feebly pleochroic in yellow tints with $X > Z$. In vertical reflected light gray.

Occur.—In metalliferous veins; forms only from acid solutions; the stable form of ZnS above 1020° C., but inverts very slowly at lower temperatures. Inversion temperature lowered to 880° C. by 28 per cent FeS. Formed artifically only above 200° C. Rare.

Diag.—Distinguishable only by optical properties from sphalerite when crystal form is lacking, but fibrous condition is suggestive of wurtzite.

Greenockite (CdS) is hexagonal with $c = 0.8109$. Crystals hemimorphic, short prismatic, with distinct prismatic cleavage. H. = 3. G. = 4.82. Sublimes in N at 980° C. Soluble in HCl. Uniaxial positive with $N_o = 2.506$ Na, $N_e = 2.529$, $N_e - N_o = 0.023$ (art. cryst.). But for $\lambda = 523$ the mineral is isotropic and at the blue end of the spectrum it is uniaxial and negative. Natural crystals gave $N_o = 2.582$ red, $N_e - N_o =$ weak; sometimes distinctly biaxial. Color yellow of various shades. Found in cavities in basic igneous rocks, but more common in zinc ore deposits in small amounts, coloring smithsonite or coating sphalerite. Rare.

CINNABARITE (*Cinnabar*) Hexagonal $c = 1.1453$ HgS

Phys. Char.—Crystals usually thick tabular or rhombohedral; also prismatic. Twinning on 0001. Perfect prismatic cleavage. H. = 2–2.5. G. = 8.176. Sublimes at 580° C. in the absence of oxygen.

Opt. Prop.—Uniaxial positive; refringence, birefringence and dispersion all remarkably high. Circular polarization produced. $N_o = 2.913$ Na, $N_e = 3.272$, $N_e - N_o = 0.359$.

Color bright red, brownish or grayish red. Absorption said to be visible in some crystals.

Inver.—*Metacinnabarite* (HgS) is a rare isometric form which is black and opaque. G. = 7.60. It is formed only from acid solutions; is unstable, and changes to cinnabarite under favorable conditions.

Occur.—Chiefly in veins; also as a product of solfataric action about hot springs. It is often associated with pyrite, stibnite, realgar, calcite, quartz, barite, fluorite, etc.

Diag.—The optical properties are quite characteristic; also the red color and volatility.

PYRRHOTITE Hexagonal $c = 0.863$ to 0.874 FeS(+S)

Phys. Char.—Crystals commonly hexagonal prisms or basal plates. Twinning on $10\bar{1}1$ rare. Basal cleavage or parting. H. = 3.5–4.5. G. = 4.77 (*troilite* [15]) to 4.53 (with 6 per cent extra S). Fuses at 1170° C. to black magnetic mass. Soluble in HCl. Pyrrhotite is magnetic, but to a very variable degree.

Opt. Prop.—Opaque. Produces marked rotation of the plane of polarization of reflected light. Color between bronze yellow and copper red, darker than pyrite; subject to tarnish. Cream color in vertical reflected light.

Inver.—The stable form above 130° ±C. is orthorhombic with $a : b : c = 0.579 : 1 : 0.927$ (to 0.993); twinning on 023 common; often elongated parallel to a. Inversion is not easily accomplished and both forms occur in nature.

Alter.—In the presence of sulphur or alkaline sulphides in solution pyrrhotite tends to change to pyrite, especially at temperatures of 100°–300° C. In air pyrrhotite alters rather easily to limonite.

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[15] According to A. S. Eakle (*Am. Mineral.*, VII, 1922, p. 77) troilite differs from pyrrhotite in being non-magnetic, with G. = 4.67, and in being readily soluble in H_2SO_4.

OCCUR.—Pyrrhotite is found in basic, and especially nephelinitic, igneous rocks, and, much more rarely, in acid types. It also occurs in amphibolite and crystalline schists. Further, it is found in rocks produced by contact metamorphism. The largest masses and best crystals are found in metalliferous veins. Finally, it occurs in meteorites; in stony meteorites pyrrhotite occurs, in iron meteorites troilite occurs. Troilite has the composition FeS, and forms only in the presence of excess iron.

DIAG.—Distinguished from pyrite by the color, the crystal form, the density, the magnetism, and the attack by HCl.

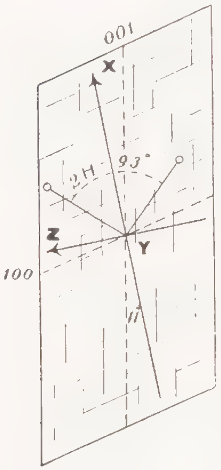


FIG. 16.—Optic orientation of realgar.

REALGAR

MONO. $a : b : c = 0.720 : 1 : 0.486 \quad \beta = 66° 16'$ AsS

PHYS. CHAR.—Crystals short, prismatic, vertically striated with distinct 010 cleavage. H. = 1.5–2. G. = 3.56. F. = 1. (310° C.). Wholly volatile. Soluble in alkalies.

OPT. PROP.—Optic plane is 010; $X \wedge c = +11°$. Inclined dispersion strong with $\rho > v$ very strong, giving abnormal interference colors near extinction. $(-)2V = 40° \pm$ Li. $N_g = 2.61$ Li, $N_m = 2.59$, $N_p = 2.46$, $N_g - N_p = 0.15$.

Color aurora-red to orange yellow; streak paler. In thin section pleochroic with X = orange red to nearly colorless, Y = Z = pale golden yellow to vermilion red.

ALTER.—Changes on exposure to light to orpiment and arsenolite.

OCCUR.—With silver and lead ores in veins; also in clay and in slate; often produced by solfataric action; also from geysers.

DIAG.—Distinguished from orpiment by its inclined extinction and pleochroism, from cinnabar by its negative biaxial character and pleochroism.

5. DISULPHIDES, ETC., OF DIVALENT(?) ELEMENTS

PYRITE ISOMETRIC FeS_2

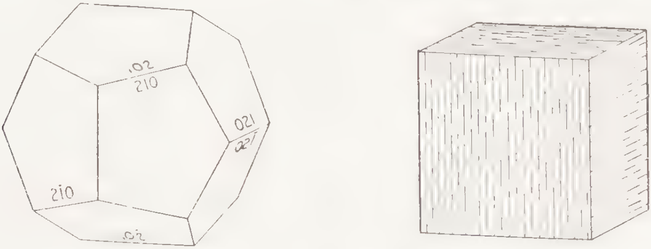
PHYS. CHAR.—Crystals commonly cubes, pyritohedrons or octahedrons; faces often striated parallel to the edge 100 : 210. Twinning usually by penetration with *a* as the twinning axis. H. = 6–6.5. G. = 5.02. In the closed tube gives a sulphur sublimate and a magnetic residue. Burns with a blue flame. Insoluble in HCl; decomposed by HNO_3

OPT. PROP.—Opaque. In inclined reflected light pale brass yellow color and brilliant metallic luster. In vertical reflected light creamy white color. Streak greenish black. Polishes with difficulty and in relief on account of the hardness.

INVER.—Marcasite changes to pyrite very slowly at 450° C.; more rapidly at 525° C.

ALTER.—Pyrite loses sulphur and changes to pyrrhotite at 665° C.

(beginning at 575° C.). This reaction is reversed at 550° C. in the presence of available sulphur. Pyrite alters in nature quite readily; the process may be one chiefly of oxidation, or it may be largely hydration. In the first case the product is hematite, or, more commonly limonite or goethite. In the second case the product is chiefly melanterite, sometimes mixed with copiapite, gypsum, halotrichite, etc. The alteration of pyrite usually results not only in the formation of new iron minerals, but also in the production of free sulphuric acid; therefore, altered pyrite is often accompanied by various other sulphates formed by the action of this free acid on surrounding minerals. Gypsum is very commonly produced in this way; in other cases the product may be alunogenite, halotrichite, or still other sulphates.



FIGS. 17–18.—Crystal forms of pyrite.

OCCUR.—Pyrite occurs under many varying conditions; it is one of the most widely distributed of minerals. Thus, it is found in many igneous rocks, usually in very small amount; it occurs in various metamorphic rocks likewise in small amount; it is found in some purely sedimentary rocks, in some cases being evidently of contemporaneous origin, but more frequently being deposited in the rock at a later date; finally, it is found often in abundance in many ore deposits, and hot spring deposits. Pyrite forms artificially from alkaline solutions at moderate temperatures or at high temperatures under pressure; it also forms from acid solution.

DIAG.—Pyrite is distinguished from many opaque minerals by the pale brass yellow color and metallic luster; distinguished from chalcopyrite by paler color and greater hardness, giving poorer polish. Pyrrhotite has a pale bronze yellow color, is softer than pyrite, and is readily attacked by HCl, which pyrite resists. Difficult to distinguish from marcasite in the absence of crystal form, but marcasite has a slightly paler color, a lower density, and alters more readily.

Hauerite (MnS_2) is isometric, often in octahedrons with indistinct cubic cleavage. H. = 4. G. = 3.46. F. = 3. Soluble in HCl. Isotropic with N = 2.69 Li. Color brownish black; red in powder. Found in clay and schist. Rare.

MARCASITE ORTH. $a : b : c = 0.766 : 1 : 1.235$ FeS_2

PHYS. CHAR.—Crystals 001 tablets or pyramidal. More commonly in masses of various shapes with radiating or fibrous texture. Twinning on 110, sometimes repeated; twinning on 101 less common. Prismatic cleavage distinct. H. = 6.0–6.5. G. = 4.887. On charcoal burns with sulphurous odor. Decomposed by HNO_3.

OPT. PROP.—Opaque. In inclined reflected light pale bronze yellow color and metallic luster. Polishes with difficulty and in relief. In vertical reflected light creamy white color. Produces marked rotation of the plane of polarization of reflected light, in which it has a peculiar and characteristic pleochroism.

INVER.—Changes to pyrite very slowly at 450° C.; more rapidly at 525° C.

ALTER.—Alters by oxidation much more rapidly than pyrite, and gives rise to melanterite, or, less commonly copiapite. At the same time free sulphuric acid is produced, which is an active agent in some of the processes of secondary enrichment of ore deposits. At other times marcasite alters to limonite, or goethite, or hematite, sometimes with the production of free sulphur.

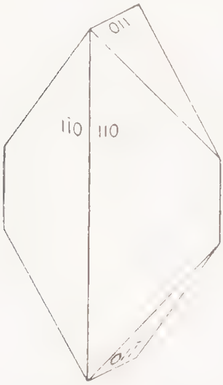


FIG. 19.—A crystal habit of arsenopyrite.

OCCUR.—Abundant in clay in coal formations; in metalliferous veins in all kinds of rocks with copper, lead, zinc, etc.; in veins and disseminations in limestones. Forms only from acid solutions at temperatures below 450° C.

Arsenopyrite[15a] or *mispickel* (FeAsS) is also orthorhombic with $a : b : c = 0.677 : 1 : 1.188$. Crystals prismatic or modified. Twinning like marcasite. Distinct prismatic cleavage. H. = 5.5–6. G. = 5.9–6.2. F. = 2, to magnetic globule. Strikes fire with steel giving an alliaceous odor. Decomposed by HNO_3. Opaque. Color silver white, sometimes grayish. In vertical reflected light has white color. Polished surface effervesces with HNO_3 and quickly tarnishes to deep brown. Found especially in veins, commonly associated with ores of silver, lead, tin, gold.

[15a] Arsenopyrite is an arsenide-sulphide related to marcasite.

6. SULPHIDES, ETC., OF TRIVALENT ELEMENTS

STIBNITE (*Antimonite*) ORTH. $a : b : c = 0.993 : 1 : 1.018$ Sb_2S_3

PHYS. CHAR.—Crystals long prismatic, vertically striated, with perfect 010 cleavage. H. = 2. G. = 4.52–4.62. F. = 1. (546° C.). Soluble in HCl.

OPT. PROP.—Nearly opaque, but translucent to red and infra red rays; in such light the optic plane is 100, $X = c$. For 762 $\mu\mu$:—$(-)2V = 25° 45'$, $N_g = 4.303$, $N_m = 4.046$, $N_p = 3.194\pm$, $N_g - N_p = 1.109\pm$. In vertical reflected light galena white; produces marked rotation of the plane of polarization of reflected light.

Color and streak steel gray, subject to black tarnish. Luster metallic, often splendent.

ALTER.—Oxidation of stibnite produces kermesite or valentinite.

OCCUR.—Common in veins with sphalerite, galena, cinnabar, barite, quartz, etc. Also found disseminated in limestone.

DIAG.—Opaque except in red light; extreme refringence and birefringence; vertically striated crystals of bright metallic luster.

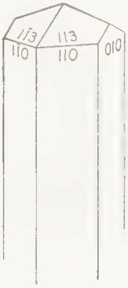


FIG. 20.—A crystal habit of stibnite.

ORPIMENT MONO. $a : b : c = 0.5962 : 1 : 0.6650$ $\beta = 89° 19'$ As_2S_3

PHYS. CHAR.—Crystals small, with micaceous 010 cleavage; laminæ flexible, inelastic. H. = 2. G. = 3.4. F. = 1. (320° C.). Wholly volatile. Soluble in H_2SO_4.

OPT. PROP.—Optic plane is 001; $Z = a$. $(+)$ $2E = 70° 24'$ D, $\rho > v$ strong, $N_g = 3.0\pm$, $N_m > 2.72$ Li, $N_p = 2.4\pm$, $N_g - N_p = 0.6\pm$.

Color lemon yellow. Pleochroic in thick plates in yellow tints with X > Y and Z.

OCCUR.—In hot spring and geyser deposits, in veins, and in deposits from volcanic gases. Also formed by sublimation in burning coal mines. A common artificial product, sometimes called King's yellow.

DIAG.—The micaceous cleavage, yellow color, volatile character, and extreme birefringence are characteristic.

7. SULPHIDES, ETC., OF TETRAVALENT (?) ELEMENTS

MOLYBDENITE HEXAGONAL $c = 1.908$ MoS_2

PHYS. CHAR.—Crystals basal plates or short prismatic, with perfect basal cleavage; laminæ flexible inelastic. H. = 1–1.5. G. = 4.7–4.8. F. = 7 (at 1500° C.?). Decomposed by HNO_3.

OPT. PROP.—Opaque. Index about 4.7 for Na light.[16] Color lead gray. Streak slightly greenish (on glazed porcelain). In vertical reflected light grayish white.

OCCUR.—Embedded or disseminated in crystalline limestone, gneiss, vein quartz, granite, etc. Alters easily to molybdite.

8. SULPHIDES OF TRIVALENT AND MONOVALENT ELEMENTS "SULPHOSALTS"

BORNITE ISOMETRIC Cu_5FeS_4?

COMP.—Composition varies to about Cu_3FeS_3; component molecules unknown.

PHYS. CHAR.—Crystals cubic or modified. H. = 3. G. = 4.9–5.2. F. = 2. Soluble in HNO_3 with separation of sulphur.

OPT. PROP.—Opaque. Color reddish brown, only seen on fresh fracture, which tarnishes quickly to red and blue. In vertical reflected light pinkish brown. May produce (anomalous) slight rotation of the plane of polarization of reflected light according to M. N. Short.

OCCUR.—Chiefly in veins with chalcopyrite, chalcocite, etc.; also in pegmatites. Formed by action of hot spring water on coins; also in copper furnaces.

TETRAHEDRITE ISOMETRIC $Cu_6Sb_2S_6 + m(Fe, Zn)_6Sb_2S_9$?

COMP.[17]—Arsenic is usually present and thus there is a gradation to *tennantite*. Further, more or less copper may be replaced by silver, etc.

PHYS. CHAR.—Crystals tetrahedral, often modified. Twinning on 111, or, rarely on 100. Cleavage none. H. = 3–4. G. = 4.4–5.1 F. = 1.5. Decomposed by HNO_3.

OPT. PROP.—Opaque to translucent. $N > 2.72$ Li. Color gray to iron black, rarely purple. Streak gray to brown or red. In thin section bright red to opaque. Luster metallic, often splendent. Grayish (brownish) white in vertical reflected light.

OCCUR.—Found chiefly in veins with other copper ores, and with pyrite, galena, sphalerite, and various silver and gold ores.

CHALCOPYRITE TETRAGONAL $c = 0.985$ $CuFeS_2$

PHYS. CHAR.—Crystals commonly tetrahedral in aspect, often striated. Twinning on 111. H. = 3.5–4. G. = 4.1–4.3. F. = 2, to magnetic globule. Soluble in HNO_3 leaving a residue of S.

OPT. PROP.—Opaque. Color brass yellow, often tarnished. In inclined reflected light has metallic luster; brass yellow color; in vertical reflected light yellow. Polishes readily. Produces no visible rotation of the plane of polarization of reflected light.

ALTER.—Chalcopyrite may oxidize to sulphate; other alteration products include malachite, chrysocolla, limonite.

OCCUR.—Chalcopyrite is the most widely disseminated ore of copper. It occurs frequently in veins with other copper minerals; it is also found disseminated in crystalline schists and gneiss, and in serpentine. Less commonly it is found in igneous rocks. It is produced by the action of hot springs upon copper coins, and is sometimes formed in metallurgical furnaces.

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[16] E. P. Tyndall: *Phys. Rev.*, XXI, 1923, p. 162.

[17] A. N. Winchell: *Am. Mineral.*, XI, 1926, p. 181.

Trechmannite ($AgAsS_2$) is trigonal with $c = 0.653$; crystals small prismatic with rhombohedral and basal cleavages. H. = 1.5–2. Uniaxial negative with $N_o = 2.6$ Li, $N_e = ?$, $N_o - N_e =$ extreme. Color and streak scarlet. Pleochroic: X = nearly colorless, Z = pale red. Found in dolomite in Binnenthal, Switzerland. Very rare.

PYRARGYRITE TRIGONAL $c = 0.789$ Ag_3SbS_3

PHYS. CHAR.—Crystals commonly prismatic and hemimorphic; twinning common on $10\bar{1}4$ either as simple or multiple twins; twinning on $10\bar{1}1$ uncommon. Distinct rhombohedral cleavage. H. = 2.5. G. = 5.77–5.86. Fusible with spurting at 1. Decomposed by HNO_3, but only partly soluble.

OPT. PROP.—Uniaxial negative with $N_o = 3.084$, $N_e = 2.881$, $N_o - N_e = 0.203$.

Color black to grayish black. Streak purplish red. In thin section red. Grayish white in vertical reflected light. Produces a slight rotation of the plane of polarization of reflected light, not easily seen.

OCCUR.—Found in veins with other silver ores and with galena, sphalerite, tetrahedrite, etc.

Proustite (Ag_3AsS_3) is isomorphous with pyrargyrite, with $c = 0.804$. Crystals often acute rhombohedral with distinct rhombohedral cleavage. H. = 2–2.5. G. = 5.57–5.64. Easily fusible. Decomposed by HNO_3. Uniaxial negative; $N_o = 3.087$, $N_e = 2.792$, $N_o - N_e = 0.295$. Color scarlet to aurora red. In thin section bright red with weak pleochroism: X = cochineal red, Z = blood red. More pellucid than pyrargyrite. Bluish white in vertical reflected light. Occurs with pyrargyrite.

Polybasite ($Ag_{16}Sb_2S_{11}$?) is monoclinic with $a : b : c = 1.731 : 1 : 1.580$, $\beta = 90° 0'$; copper commonly replaces some silver; arsenic replacing antimony leads gradually to *pearceite*. Crystals six-sided tabular prisms. Twinning on 110 common. Imperfect basal cleavage. H. = 2–3. G. = 6.1. F. = 1 with spurting. Decomposed by HNO_3. Optic plane is 100; $X = c$. $(-)2E = 70° \pm$, $N_m = 3 \pm$, $N_g - N_p =$ very strong. Produces marked rotation of the plane of polarization of reflected light. Color and streak black; cherry red in section. Grayish white in vertical reflected light. Found in veins with silver and copper ores. Rare.

Miargyrite ($AgSbS_2$) is monoclinic with $a : b : c = 2.994 : 1 : 2.909$, $\beta = 81° 23'$; crystals small tabular or prismatic with difficult 010 cleavage. H. = 2–2.5. G. = 5.2. F. = 1. Decomposed by HNO_3. Nearly opaque; optic orientation unknown. $(+)2V$ = moderate. $N_p > 2.72$ Li, $N_g - N_p =$ very strong. Color iron black; streak cherry red. In section dark blood red; absorption distinct. Bluish white in vertical reflected light. Found in ore deposits, as at Randsburg, Calif. Rare.

Smithite ($AgAsS_2$) is monoclinic with $a : b : c = 2.221 : 1 : 1.957$, $\beta = 78° 48'$. Crystals tabular, apparently hexagonal with perfect 100 cleavage. H. = 1.5–2. G. = 4.88. Optic plane is 010; $Z \wedge c = +4°$ Li and $+6.5°$ Na. Optic sign negative; optic angle (2V) supposed to be about 65° Na, but light is internally reflected on account of extreme refringence ($N = 3.27$?). Color and streak scarlet vermilion, altering to orange-red on exposure. Found in Binnenthal, Switzerland. Rare.

Lorandite ($TlAsS_2$) is monoclinic with $a : b : c = 1.329 : 1 : 1.078$, $\beta = 52° 27'$. Crystals tabular or prismatic, highly modified. Perfect 100 and distinct 001 cleavages. H. = 2–2.5. G. = 5.53. F. = 1. Volatile. Soluble in HNO_3. Optic plane normal to 010; Y nearly = a; $Z = b$. 2E = large, probably positive. $N_p > 2.72$, $N_g - N_p =$ extreme. Color cochineal red; deep red in powder. Weakly pleochroic with Y = purple red, Z = red-orange. Gray in vertical reflected light. Found on realgar in Macedonia. Very rare.

9. OTHER DOUBLE SULPHIDES—"SULPHOSALTS"

ENARGITE ORTH. $a : b : c = 0.871 : 1 : 0.825$ Cu_3AsS_4

PHYS. CHAR.—Crystals prismatic vertically striated with perfect 110 cleavage. H. = 3. G. = 4.44. F. = 1. Soluble in HNO_3.

OPT. PROP.—Opaque. Color and streak grayish black. Produces marked rotation of the plane of polarization of reflected light. Brownish white in vertical reflected light.

OCCUR.—Important in some copper mines, as at Butte.

Hutchinsonite ($Tl_2PbAs_4S_8$?) is orthorhombic with $a : b : c = 0.817 : 1 : 0.755$; crystals flattened prisms, complex, with distinct 100 cleavage. H. = 1.5–2. G. = 4.6. Optic plane is 100; X normal to 010. $(-)2V = 37° 34'$ Na, $\rho < v$ extreme. $N_g = 3.188$, $N_m = 3.176$, $N_p = 3.078$, $N_g - N_p = 0.110$. Color and streak scarlet to vermilion; pleochroism weak. Found in the Binnenthal, Switzerland, in dolomite. Rare.

Livingstonite ($HgSb_4S_7$) is orthorhombic (?) in prismatic crystals with prismatic cleavage at nearly 90°. H. = 2. G. = 4.81. F. = 1. Volatile. Decomposed by HNO_3 with separation of Sb_2O_3. Biaxial; probably negative; Z = c. N_g = ?, $N_m = 3 \pm$, $N_p > 2.72$, $N_g - N_p$ = extreme. Nearly opaque. Color lead gray; streak red. Microscopic prisms are red with slight absorption, X > Z. Galena white in vertical reflected light. Found in Mexico with sulphur, cinnabarite, etc. Very rare.

10. OXYSULPHIDES

Voltzite ($4ZnS \cdot ZnO$) is hexagonal in lamellar or finely fibrous compact globular forms. H. = 4–4.5. G. = 3.7. F. = 7. Attacked by HCl. Uniaxial positive with $N_o = 2.03 \pm$, $N_e - N_o$ = rather strong. Alters in immersion liquids. Color dirty rose-red, yellow or brown. Brown in inclined reflected light. Gray in vertical reflected light. Very rare.

Kermesite (Sb_2S_2O) is monoclinic (?) with $a : b : c = 3.965 : 1 : 0.853$, $\beta = 90° 0'$. Crystals prismatic parallel to b with perfect 100 and distinct 101 cleavages. Sectile. H. = 1-1.5. G. = 4.5. F. = 1. (517° C.). Volatile. According to Larsen Z is parallel to elongation; (+) 2V = small (?). N_g = (?). $N_m > 2.72$, $N_p = 2.74$, $N_g - N_p$ = extreme. According to Pjatnitzky,[18] Y is parallel to elongation (= b). $Z = c \pm$; absorption weak, X > Y > Z. Color cherry red; needles brownish red. Alteration product of stibnite. Rare.

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[18] *Zeit. Kryst.*, XX, 1892, p. 430.

III. HALIDES

The halides are classified as simple halides and oxyhalides, and then arranged in the order of increasing valence of the metallic element, and in that of decreasing symmetry.

1. HALIDES OF MONOVALENT BASES

HALITE GROUP

The halite group consists of isometric minerals composed of a halogen with a univalent metal or ammonium. They all have the structure shown in Fig. 1 of Part One of this work. The cubic form is common.

HALITE Isometric NaCl

Phys. Char.—Crystals usually cubic with perfect 100 cleavage. Percussion figure on 100 with rays parallel to the binary axes of symmetry. H. = 2.5. G. = 2.17. Easily fusible, often with decrepitation (at 802° C.). Soluble in H_2O; taste saline.

Opt. Prop.—Usually isotropic; sometimes slightly anisotropic. Refringence low; N = 1.5443 D. Colorless, white, yellowish, reddish, bluish. The red color is due to the ferruginous inclusions, the blue color is probably due to metallic sodium in a dispersoid condition.

Incl.—Besides sodium and iron compounds, inclusions of gypsum, anhydrite, shale are common. Further, liquid inclusions often in "negative crystals" are not rare; they often contain gas bubbles, which may be movable. Such inclusions are sometimes megascopic in size.

Occur.—Chiefly in sedimentary deposits formed from evaporation in estuaries or in salt lakes. Occurs in rocks of various ages associated with gypsum, anhydrite, polyhalite, carnallite, glauberite, etc. Found rarely about volcanoes.

Villiaumite (NaF) has cubic cleavage with H. = 3.5. G. = 2.79. Soluble in hot water. At ordinary temperatures it has very weak negative birefringence with X normal to 001. The refringence is negative (N = 1.328) producing marked relief. Except when heated it is colored red to violet and is pleochroic with X = golden yellow and Z = carmine red. Found in nepheline syenite in Guiana; very rare.

Sylvite (KCl) is similar in form and cleavage. H. = 2. G. = 1.98. Fuses with violet flame color. Soluble in H_2O; taste saline. Optically like halite, but N = 1.4904 D. Colorless, white or tinted by inclusions. Found in salt lake deposits with halite and carnallite; also formed about volcanoes.

Salammonite (NH_4Cl) is also isometric; twinning on 111. Imperfect 111 cleavage. H. = 1.5–2. G. = 1.528. Reversible inversion at 156° C. with increase of volume, but no change of symmetry. Sublimes without fusion. Soluble in H_2O. Isotropic with N = 1.6422 D. Color white, yellowish, grayish. Found about volcanoes, near ignited coal seams, and in guano.

Nantokite (CuCl) has cubic cleavage. H. = 2–2.5. G. = 3.93. Oxidizes readily in moist air. Soluble in water. Isotropic with N = 1.93. Colorless. Found at a copper mine in Chile. Very rare.

Marshite (CuI) is tetrahedral with dodecahedral cleavage. H. = 2.5. G. = 5.59. F. = 1.5(?) Isotropic with N = 2.313 Li, 2.346 Na, 2.383 Tl, the dispersion being greater than that of diamond. Color oil-brown, pale yellow to brick red; streak always bright lemon yellow. Becomes dark red and birefringent on heating. Found with cerussite, psilomelane, limonite, etc., at Broken Hill mines, New South Wales. Very rare.

Miersite ($4AgI \cdot CuI$) has the same form and cleavage as marshite, with twinning on 111. H. = 2. G. = 5.64. Soluble in NH_4OH. Described as a definite compound, but may be a crystal solution. Isotropic with N = 2.20. Color yellow. Found with cerussite, limonite, malachite, etc., at Broken Hill mines, New South Wales. Very rare.

Cerargyrite is the name of all kinds of "horn silver" or isometric silver halides; the chief subspecies are *chlorargyrite* (AgCl) and *bromyrite* (AgBr), with the intermediate type *embolite* [Ag(Cl, Br)] and the variant *iodembolite* [Ag(Cl, Br, I)]; miersite is related. Crystals are cubic without cleavage; twinning on 111; usually massive, encrusting. H. = 1-2. G. = 5.4–6. Soluble in NH_4OH. Sectile. The subspecies all have very high refringence and variable properties as follows: *Chlorargyrite*, G. = 5.55. Fuses at 452° C. After fusion, N = 2.061. Color pearl gray, grayish green or white, becoming violet in sunlight. *Embolite*, G. = 5.8, fuses at 412° ± C. After fusion, N = 2.15 ±. Gray to yellow or yellowish green, becoming dark in sunlight. *Iodembolite*, G. = 5.7. N = 2.20 ±. Sulphur yellow, sometimes greenish. *Bromyrite*, G. = 6.0, fuses at 422° C.; after fusion N = 2.254. Color yellow, amber, slightly greenish; little change in sunlight. All are found in the oxide zone of silver deposits, often with ores of copper, lead, etc.

Calomel (Hg_2Cl_2) is tetragonal with $c = 1.723$; crystals pyramidal or basal plates; often highly complex; distinct 100 cleavage. H. = 1–2. G. = 6.48. Infusible, but volatile. Soluble in aqua regia. Uniaxial positive. Refringence very high; birefringence twice as strong as in any other known mineral except stibnite. $N_o = 1.973$ Na, $N_e = 2.656$, $N_e - N_o = 0.683$. Color white, yellowish, grayish, brown. Found in the oxide zone of ore deposits. Rare.

IODYRITE HEXAGONAL $c = 0.820$ AgI

PHYS. CHAR.—Crystals prismatic, hemimorphic. Twinning rare on $30\bar{3}4$. Also massive and lamellar. Perfect 0001 cleavage; lamellæ flexible. Soft, sectile. G. = 5.6. Fuses at 527° C., giving fumes of I and Ag globules. Soluble in NH_4OH.

OPT. PROP.—Uniaxial positive with $N_o = 2.21$ (2.18), $N_e = 2.22$, $N_e - N_o = 01$. May be slightly biaxial. Abnormal green interference colors.

Color yellow to yellowish green; sometimes brownish. Streak yellow.

INVER.—A reversible inversion to an isometric form occurs sharply at 146° C.

OCCUR.—Found in veins in silver mines. Rare.

2. ANHYDROUS HALIDES OF DIVALENT BASES

FLUORITE ISOMETRIC CaF_2

PHYS. CHAR.—Crystals usually cubic, sometimes octahedral or dodecahedral. Twinning common on 111; usually the two individuals interpenetrate. Perfect 111 cleavage. H. = 4. G. = 3.18. Fusible with red flame color. Soluble in H_2SO_4 with evolution of HF.

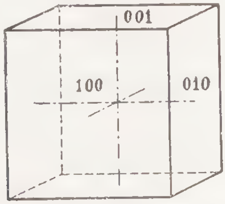

FIG. 21.—A crystal form of fluorite.

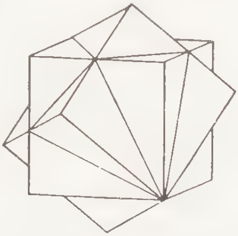

FIG. 22.—A penetration twin of fluorite.

OPT. PROP.—On account of the low index of refraction, the negative relief is marked. Fluorite often shows abnormal birefringence; Hussak describes such crystals as composed of orthorhombic individuals with X perpendicular to the cubic faces. He regards the birefringence as secondary and ascribes it to internal tension; it does not disappear at red heat.

$$N = 1.43385 \text{ Na (remarkably constant}^1\text{)}.$$

Color often bright; yellow, blue, purple, white, green, red, brown. The color of fluorite is not uniformly distributed. It is probably in some cases due to small quantities of oxides of iron and manganese, but in other cases to other inclusions, notable dispersoidal calcium, or fluorine, or hydrocarbons.

OCCUR. Fluorite is rarely found as a primary constituent of igneous rocks; in certain cases it seems to have been formed in igneous rocks through the action of fumaroles. Common in veins associated with quartz and barite, and also in some metalliferous veins. Finally, it is found in sedimentary and metamorphic rocks.

DIAG.—The crystal form, octahedral cleavage, very low refringence, vitreous luster, softness, and ready fusibility are useful diagnostics. Color, when present, is not uniformly distributed.

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[1] H. E. Merwin: *Am. Jour. Sci.*, CLXXXII, 1911, p. 429.

Hydrophilite ($CaCl_2$) is isomorphous with fluorite. H. = soft. G. = 2.2. Very deliquescent. Isotropic with N = 1.52. Found in salt deposits and about volcanoes. Very rare.

Sellaite (MgF_2) is tetragonal with $c = 0.66$. Crystals usually prismatic with perfect 100 and 110 cleavages. H. = 5. G. = 3.17. Fusible with intumescence at 1221° C. Soluble in pure H_2SO_4. Uniaxial positive [2] with $N_o = 1.3780$, $N_e = 1.3897$, $N_e - N_o = 0.0117$. Colorless. Found in anhydrite or sulphur; also with fluorite. Very rare. Differs from scapolite by its easy cleavages and its optic sign.

Chloromagnesite ($MgCl_2$) forms hexagonal basal plates, and fibers. Soft. Very deliquescent. F. = 1. Uniaxial negative with $N_o = 1.675$, $N_e = 1.59$, $N_o - N_e = 0.085 \pm$. Colorless. Found about volcanoes. Very rare.

Cotunnite ($PbCl_2$) is orthorhombic with $a : b : c = 0.595 : 1 : 1.187$. Crystals tabular parallel to 010; also acicular parallel to a. Perfect 001 cleavage. Soft. G. = 5.84. F. = 1. Soluble in hot water. Optic plane is 010; $Z = c$. (+) $2V = 67°$ Na, $N_g = 2.260$ Na, $N_m = 2.217$, $N_p = 2.199$, $N_g - N_p = 0.061$. Color white, greenish, yellowish. Found about volcanoes. Very rare.

3. HYDROUS HALIDES OF DIVALENT BASES

Tachyhydrite ($Mg_2CaCl_6 \cdot 12H_2O$) is trigonal with $c = 1.90$, and distinct rhombohedral cleavage. Soft. G. = 1.67 (?). F. = 1. Very deliquescent. Uniaxial negative with $N_o = 1.522$, $N_e = 1.513$, $N_o - N_e = 0.009$. Color wax to honey yellow. Found in salt deposits with carnallite, anhydrite, etc.

Bischofite ($MgCl_2 \cdot 6H_2O$) is monoclinic with $a : b : c = 1.387 : 1 : 0.854$, $\beta = 86° 18'$. Crystals fibrous or granular. H. = 1.5. G. = 1.59. Fusible. Soluble in water. Optic plane and X normal to 010; $Y \wedge c = +9.5°$. (+) $2V = 79°$, $\rho > v$, weak. Crossed dispersion about X distinct. $N_g = 1.528$, $N_m = 1.507$, $N_p = 1.495$, $N_g - N_p = 0.033$. Colorless. Found in salt deposits in Prussia, etc. Very rare.

4. HALIDES OF TRIVALENT BASES

Fluocerite[3] {(Ce, La, Di)F_3} is hexagonal with $c = 1.374$; crystals prismatic or tabular. Perfect basal cleavage. H. = 4. G. = 5.7–6.1. F. = 7. Soluble in H_2SO_4. Uniaxial negative with $N_o = 1.612–1.618$, $N_e = 1.607–1.611$, $N_o - N_e = 0.004–0.007$. Color yellow to red; wax yellow in powder. Found in pegmatite in Colorado and Sweden. Very rare.

Chloraluminite ($AlCl_3 \cdot 6H_2O$) is trigonal with $c = 0.534$. Deliquescent in air. Very soluble in water. Uniaxial negative with $N_o = 1.6 +$, $N_o - N_e = 0.053$. Colorless, yellowish. Found about volcanoes. Very rare.

Fluellite ($AlF_3 \cdot H_2O$) is orthorhombic with $a : b : c = 0.770 : 1 : 1.878$. Crystals pyramidal with indistinct pyramidal cleavage. H. = 3. G. = 2.17. F. = 7. Insoluble. Optic plane is 100; $Z = c$. (+) $2V = 85°$, $\rho < v$ distinct, $N_g = 1.511$, $N_m = 1.490$, $N_p = 1.473$, $N_g - N_p = 0.038$. Colorless. Found in Cornwall on quartz. Very rare.

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[2] Pelloux (*Rend. Accad. Linc.*, XXVIII, 1919, p. 284) gives $N_o = 1.37$, $N_e = 1.38$.

[3] *Geol. För. Förh. Stockholm*, XLIII, 1921 p. 19.

5. ANHYDROUS HALIDES OF DIVALENT AND MONOVALENT BASES

RINNEITE TRIGONAL $c = 0.571$ $NaCl \cdot 3KCl \cdot FeCl_2$

PHYS. CHAR.—Crystals rhombohedral; granular; fair prismatic cleavage. H. = 3. G. = 2.35. F. = easy. Soluble in water. $FeCl_2$ is soluble in alcohol leaving the rest undissolved.

OPT. PROP.—Uniaxial positive with abnormal interference colors on account of strong dispersion of birefringence. The birefringence increases with rise of temperature.

$N_e = 1.5842$ Li	1.5894 Na	1.5939 Tl
$N_o = 1.5836$ Li	1.5886 Na	1.5930 Tl
$N_e - N_o = 0.0006$ Li	0.0008 Na	0.0009 Tl

Colorless or stained yellow, pink, violet, brown.

OCCUR.—In salt deposits. Rare.

Chlormanganokalite [4] (K_4MnCl_6) is trigonal with $c = 0.58$. No cleavage. H. = 2.5. G. = 2.31. F. = easy. Deliquescent. Soluble in water. Uniaxial positive with $N = 1.59$, $N_e - N_o$ = very weak. Yellow. Found at Vesuvius. Very rare.

Pseudocotunnite (K_2PbCl_4) is orthorhombic (?); crystals acicular. F. = easy. Soluble in warm water. Index estimated at $N = 2 \pm$, $N_g - N_p$ = strong. Parallel extinction; positive elongation. Yellow. Found at Vesuvius. Very rare.

Chlorocalcite ($KCaCl_3$) is pseudocubic (orthorhombic?) with pseudocubic cleavage. Crystals prismatic or tabular; lamellar twinning. H. = 2.5–3. Strongly hygroscopic. Biaxial negative with optic plane parallel with pseudocubic faces. $N_m = 1.52 \pm$, $N_g - N_p$ = weak. Rare.

6. HYDROUS HALIDES OF DIVALENT AND MONOVALENT BASES

CARNALLITE ORTHORHOMBIC $a : b : c = 0.593 : 1 : 0.698$ $KMgCl_3 \cdot 6H_2O$

PHYS. CHAR.—Crystals resemble hexagonal pyramids; commonly massive. No distinct cleavage. H. = 2.7. G. = 1.6. F. = easy. Deliquescent.

OPT. PROP.—Optic plane is 010; $Z = a$. (+) $2E = 115°$, $2V = 69° 48'$, $\rho < v$ weak. $N_g = 1.4937$, $N_m = 1.4753$, $N_p = 1.4665$, $N_g - N_p = 0.0272$. Color white; reddish from hematite stain; colorless in section.

OCCUR.—In salt deposits; used as source of potash.

Douglasite ($K_2FeCl_4 \cdot 2H_2O$) is monoclinic (?); crystals small and very unstable in air. Uniaxial positive with $N_o = 1.488$, $N_e = 1.500$, $N_e - N_o = 0.012$. In powder tends to lie on face normal to optic axis. Color green. Artificial crystals are monoclinic with $a : b : c = 0.737 : 1 : 0.504$, $\beta = 75° 16'$; crystals prismatic or domatic (101) with imperfect $\bar{2}01$ cleavage and G. = 2.16. Color bluish green. Found in salt deposits with carnallite, etc. Rare.

7. ANHYDROUS HALIDES OF TRIVALENT AND MONOVALENT BASES

Cryolithionite ($Li_3Na_3Al_2F_{12}$) is isometric; crystals pyramidal; granular. Perfect 110 cleavage. H. = 3.5–4. G. = 2.78. F. = 1.5. Isotropic with $N = 1.3382$ Li, 1.3395 Na, 1.3408 Tl. Colorless. Found with cryolite in pegmatite in Greenland. Very rare.

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[4] Why not shorten this unwieldy name to the equally significant form *chlormankalite*?

Mosesite is a hydrous chloride (and sulphate) of Hg and NH_4 of unknown formula. Crystals octahedral with conchoidal fracture. Soft. Isotropic with $N = 2.065$. Also in part birefringent. Yellow. Found at Terlingua, Texas. Very rare.

Chiolite (Na_2AlF_5) is tetragonal with $c = 1.042$; crystals pyramidal with perfect 001 and distinct 111 cleavages. H. = 3.5–4. G. = 3. F. = 1.5. Uniaxial negative with $N_o = 1.3486$, $N_e = 1.3424$, $N_o - N_e = 0.0062$. Color white. Found in pegmatite in Greenland and in Ilmen Mountains.

Avogadrite [4a] (KBF_4 with about 10 per cent $CsBF_4$) is orthorhombic with $a : b : c = 0.790 : 1 : 1.283$. Crystals 001 tablets elongated parallel to b (also a). G. = 2.62. The optic plane is 010; $X = c$. (−) $2V$ = very large, $N = 1.326$, $N_g - N_p$ = very weak. Colorless. Found at Vesuvius.

CRYOLITE MONOCLINIC $a : b : c = 0.966 : 1 : 1.388$ $\beta = 89° 49'$ Na_3AlF_6

PHYS. CHAR.—Crystals cubic in aspect by development of 001 and 110. Also massive, cleavable. Twinning on 110 as contact twins and as multiple lamellar twins; similarly, on 112 and 100. Pseudocubic cleavage with 001 perfect and 110 good; $\bar{1}01$ also good. H. = 2.5. G. = 2.95–3.0. Fusible at 920° C. Soluble in H_2SO_4 with evolution of HF. Soluble in 2730 parts of water.

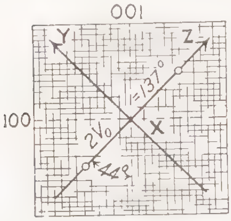

FIG. 23.—Optic orientation of cryolite.

OPT. PROP.—The optic plane and X are normal to 010; $Z \wedge c = -44°$. The refringence is low, giving marked relief. Strictly isotropic above 570° C. (+) $2E = 59°$, $2V = 43°$, $\rho < v$, with horizontal dispersion. $N_g = 1.3396$ Na, $N_m = 1.3389$, $N_p = 1.3385$, $N_g - N_p = 0.0011$ Na. Colorless to snow white; also stained reddish, brown, black.

INVER.—Reversible inversion to an isometric form [4b] at about 560° C.

ALTER.—Several hydrous fluorides form by alteration, these include *pachnolite*, *thomsenolite*, *prosopite* and *gearksutite*.

OCCUR.—Cryolite is found in large amount in a pegmatite in gneiss in west Greenland associated with quartz, fluorite, siderite, cassiterite, galena, molybdenite, etc. Also known in pegmatite with quartz, microcline and zircon near Pike's Peak, and in a topaz mine in the Ilmen Mountains.

DIAG.—Easily distinguished by its very low refringence, weak birefringence, good cleavages, and extinction at large angles with the cleavages.

8. HYDROUS HALIDES OF TRIVALENT AND MONOVALENT BASES

Erythrosiderite ($K_2FeCl_5 \cdot H_2O$) is orthorhombic with $a : b : c = 0.691 : 1 : 0.718$. Crystals tabular parallel to 100; also crusts. G. = 2.32. Very deliquescent. Optic plane is 001; $X = a$; (−) $2E = 130°$ + with very strong dispersion, $\rho < v$. Index estimated at 1.68; $N_g - N_p$ = strong. Color red; yellow in section, not pleochroic, or weakly so, with Y = reddish yellow, and X = Z = brownish yellow tinged with green. Found at Vesuvius, etc. Very rare.

Prosopite $\{CaF_2 \cdot 2Al(F, OH)_3 \cdot H_2O\}$ is monoclinic with $a : b : c = 1.319 : 1 : 0.595$ and $\beta = 85° 40'$. Tabular parallel to 010; 211 cleavage distinct. H. = 4.5. G. = 2.88. F. = 7. Decomposed by H_2SO_4. Optic plane is 010; $Z \wedge c = -50°$; Z nearly parallel to edge made by cleavages (211 and 2$\bar{1}$1). (+) 2E = 104° 14′ Li, 102° 50′ Na, 96° 24′ blue. 2V = 63°. $N_g = 1.510$, $N_m = 1.503$, $N_p = 1.501$, $N_g - N_p = 0.009$. Colorless. Alteration product of cryolite. Rare.

[4a] F. Zambonini: *Atti Accad. Lincei Rom.* (6), III, 1926, p. 644.

[4b] R. Nacken: *Cent. Min.*, 1908, p. 38.

Gearksutite $\{CaF_2 \cdot Al(F, OH)_3 \cdot H_2O\}$ is monoclinic, acicular or powdery. H. = 2. G. = 2.72–2.77. F. = 1.5–2. Soluble in acid. X is normal to 010; $Y \wedge c$ = very large. (−) 2V = medium. $N_g = 1.456$, $N_m = 1.454$, $N_p = 1.448$, $N_g - N_p = 0.008$. White, chalky. Alteration product of cryolite. Rare.

9. HALIDES OF TRIVALENT AND DIVALENT BASES

YTTROFLUORITE ISOMETRIC $CaF_2 \cdot mYF_3$

COMP.—Fluorite can take into crystal solution[5] up to 50 per cent YF_3 and the mix-crystals are called *yttrofluorite*. It can take into crystal solution up to 55 per cent CeF_3 and the mix-crystals are called *cerfluorite* (unknown in nature). Mix-crystals of yttrofluorite and cerfluorite are known in nature; they are called *yttrocerite*.

PHYS. CHAR.—Granular; imperfect 111 cleavage. H. = 4.5. G. = 3.55.

OPT. PROP.—Isotropic with index of refraction varying with the composition as follows:

CaF_2 =	100%	89.	83.2	87.
YF_3 =	0	10.	16.8	13.
CeF_3 =	0	1.		
N =	1.434	1.4425	1.4483	1.45

Yellow to brown or green. Color fades on exposure to light.

OCCUR.—In pegmatite in Norway. Very rare.

Yttrocerite $\{CaF_2 \cdot m(Y, Ce)F_3\}$ is similar, but commonly contains water, probably as hydroxyl replacing part of the fluorine. 111 cleavage. H. = 4.5. G. = 3.5. F. = 7. Soluble in HCl. Isotropic with N = 1.434–1.435. Color violet or blue; in section pale violet, unevenly colored. Found in pegmatite. Very rare.

Yttrocalcite $(Ca_5Y_2F_{16})$ is hexagonal with $c = 0.711$. Crystals prismatic with distinct prismatic cleavage. H. = 4 6. G. = 3.19. F. = 7. Soluble in acid. Uniaxial negative with index estimated at 1.45 and very weak birefringence. White to greenish. Found in Norway; very rare.

10. HALIDES OF TRIVALENT, DIVALENT AND MONOVALENT BASES

Ralstonite $\{NaMgAl_4(F, OH)_{15} \cdot 2H_2O\ ?\}$ is isometric; crystals octahedral with no cleavage. H. = 4.5. G. = 2.61. F. = 7. Decomposed by H_2SO_4. Isotropic with N = 1.4267. Also weakly birefringent in octahedral segments which have very large optic angle. Colorless to yellow. Found with cryolite in Greenland. Very rare.

Pachnolite $(NaCaAlF_6 \cdot H_2O)$ is monoclinic with $a : b : c = 1.163 : 1 : 1.532$, $\beta = 89° 40'$. Crystals prismatic; twinning on 100; poor basal cleavage. H. = 3. G. = 2.98. F. = 1.5. Soluble in H_2SO_4. Optic plane and X normal to 010; $Z \wedge c = +68°$. (+) 2E = 120° ±, 2V = 76°, $\rho < v$ weak; strong horizontal dispersion. $N_m = 1.413$, $N_g - N_p = 0.008$. Colorless. An alteration product of cryolite in Greenland, etc. Rare.

Thomsenolite $(NaCaAlF_6 \cdot H_2O)$ is monoclinic with $a : b : c = 0.997 : 1 : 1.033$, $\beta = 86° 48'$. Perfect basal and imperfect prismatic cleavages. H. = 2. G. = 2.98.

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[5] *Cent. Min.*, 1911, p. 373.

F. = 1.5. Decomposed by H_2SO_4. Optic plane and Z normal to 010; $X \wedge c = -52°$. (−) $2E = 69°$, $2V = 50°$, $\rho < v$ weak. $N_g = 1.415$, $N_m = 1.4136$, $N_p = 1.407$, $N_g - N_p = 0.008$. Colorless. Alteration product of cryolite. Rare.

11. ANHYDROUS HALIDES OF TETRAVALENT AND MONOVALENT BASES

Hieratite (K_2SiF_6) is isometric and octahedral with perfect 111 cleavage. G. = 2.75. Soluble in hot water. Isotropic with N = 1.339, as measured on artificial crystals which serve as a microchemical test for potassium. Found about volcanoes.

Malladrite[5a] (Na_2SiF_6) is pseudohexagonal (orthorhombic) with $c = 0.564$. Crystals prismatic with pseudohexagonal twinning. G. = 2.75. Nearly uniaxial and negative. $N_o = 1.312$, $N_e = 1.309$, $N_o = N_e = 0.003$. Colorless. Found at Vesuvius. Crystals serve as a microchemical test for sodium.

12. OXYHALIDES

Eglestonite (Hg_4OCl_2) is isometric; crystals dodecahedral with no cleavage. H. = 2.5. G. = 8.33. Volatile before the blowpipe. Decomposed by HCl. Isotropic with N = 2.49 Li. Also weakly birefringent (due to strain?). Yellow; darkens on exposure to light. Found at Terlingua, Texas. Very rare.

Percylite ($PbCuOCl_2 \cdot H_2O$) is isometric; crystals cubic with cubic cleavage. H. = 2. G. = 2.25. F. = 1. Soluble in HNO_3. Isotropic with N = 2.05; partly altered to boléite, N = 2.06, $N_g - N_p = 0.02$. Blue; sky-blue in section. Found with lead ores in oxide zone. Rare.

BOLÉITE TETRAGONAL[6] $c = 3.996$ $9PbCl_2 \cdot 8CuO \cdot 3AgCl \cdot 9H_2O$

PHYS. CHAR.—Crystals pseudocubic with perfect basal and distinct domatic (101) cleavage. H. = 2.5. G. = 4.8–5.1. F. = 1. Soluble in HNO_3.

OPT. PROP.—Uniaxial negative with $N_o = 2.04$–2.09, $N_e = 2.03 \pm$, $N_o - N_e = 0.02 \pm$. Color indigo blue; in section greenish blue. Crystals have an isotropic center supposed to be due to mingling of three twinned parts which form the borders, each part forming two opposite faces of the pseudocube. The isotropic center contains more silver than the borders.

OCCUR.—At Boléo, So. California, etc. Very rare.

Pseudoboléite ($5PbCl_2 \cdot 4CuO \cdot 6H_2O$) is tetragonal with $c = 2.023$; perfect basal and domatic (101) cleavage. H. = 2.5. G. = 4.85. F. = 1. Soluble in HNO_3. Uniaxial negative with $N_o = 2.03$, $N_e = 2.00$, $N_o - N_e = 0.032$–0.038. Color indigo blue. Found only in parallel intergrowth with boléite.

Diaboléite[7] $\{2Pb(OH)_2 \cdot CuCl_2\}$ is tetragonal with $c = 0.95$. Crystals pyramidal with perfect 001 cleavage. H. = 2.5. G. = 6.41. F. = easy. Soluble in HNO_3. Uniaxial negative with N = 1.98, $N_o - N_e = ?$ Color sky blue with X = pale blue to colorless, Z = deep blue. Found in ore deposits. Very rare.

Cumengéite ($PbCl_2 \cdot CuO \cdot H_2O$?) is tetragonal with $c = 1.62$–1.70. Distinct domatic (101) and less distinct prismatic (110) cleavages. H. = 2.5. G. = 4.67–4.88. F. = 1. Soluble in HNO_3. Uniaxial negative with $N_o = 2.041$ ($510\mu\mu$), $N_e = 1.926$ $N_o - N_e = 0.115$. Color indigo blue; purer blue in section than boléite or pseudoboléite with which it is always intergrown; differs from them also in lack of pearly luster on cleavage faces. The physical characters show distinct variations, probably due to variations in composition.

[5a] F. Zambonini and G. Carobbi: *Atti Accad. Lincei Rom* (6), IV, 1926, p. 171.

[6] Hadding (*Geol. För. Förh.*, XLI, 1919, p. 175) argues that boléite is strictly isometric.

[7] L. J. Spencer and E. D. Mountain: *Mineral. Mag.*, XX, 1923, p. 78.

Matlockite (Pb_2OCl_2) is tetragonal with $c = 1.763$; crystals basal tablets with perfect basal cleavage. H. = 3. G. = 7.2. F. = 1. Soluble in HNO_3. Uniaxial negative with $N_o = 2.15$, $N_e = 2.04$, $N_o - N_e = 0.11$. Some crystals are biaxial negative with $2E = 55° \pm$, $\rho < v$, the optic plane being 010. Color yellow or greenish. Found at lead mines; also at Vesuvius. Very rare.

Lorettoite ($Pb_7O_6Cl_2$) is probably tetragonal; massive with perfect basal cleavage. H. = 3. G. = 7.5. F. = 1. Soluble in HNO_3. Uniaxial negative with $N_o = 2.35$-2.40, $N_e = 2.33$–2.37, $N_o - N_e = 0.02$-0.03. Color orange yellow. At Loretto, Tenn. Very rare.

Schwartzembergite ($PbI_2O_6 \cdot Pb_9O_6Cl_6$) is pseudotetragonal with $c = 0.43$. Crystals very low pyramids with distinct 001 cleavage. H. = 2–2.5. G. = 7.39. F. = 1. Soluble in dilute HNO_3. Basal sections divide into biaxial sectors, 2E varying from 16° to 84°. (−) 2V = small with slight dispersion. $N_g = 2.36$ Li, $N_m = 2.35$, $N_p = 2.25$, $N_g - N_p = 0.11$. Color yellow to brown or red. Found on galena in a desert. Very rare.

Penfieldite (Pb_3OCl_4) is hexagonal with $c = 0.897$; crystals prismatic with distinct basal cleavage. F. = 1. Soluble in HNO_3. Uniaxial positive with $N_o = 2.13$, $N_e = 2.21$. $N_e - N_o = 0.08$. Color white. Found in lead slags at Laurium, Greece. Very rare.

Nocerite ($Ca_3Mg_3O_2F_8$) is hexagonal, acicular. G. = 2.96. Uniaxial negative with $N_o = 1.509$, $N_e = 1.486$, $N_o - N_e = 0.023$ (Zambonini [8]); $N_o = 1.512$, $N_e = 1.487$, $N_o - N_e = 0.025$ (Larsen). White. In volcanic bombs with fluorite. Very rare.

Koenenite ($Mg_5Al_2O_6Cl_4 \cdot 6H_2O$) is trigonal with perfect basal cleavage. Very soft. G. = 1.98. Uniaxial positive with strong birefringence like that of biotite; refringence unknown. Color red (due to enclosed hematite) to pale yellow. Decomposed by water without change of shape, the residue (Al_2O_3) being uniaxial negative with weak birefringence. Found in salt deposits with carnallite, etc. Rare.

Kleinite (Hg_2OCl_2) is hexagonal (above 130° C.) with $c = 1.664$, in short prisms, with good basal cleavage. H. = 3.5. G. = 7.98. Sublimes at 260° C. Soluble in HCl. Uniaxial positive (above 130° C.) with $N_o = 2.19$, $N_e = 2.21$, $N_e - N_o = 0.02$. This form may persist (metastable) to ordinary temperature. Color yellow or orange. Inverts at 130° C. (on cooling) to a biaxial negative, probably triclinic form, with $N_g = 2.18$, $N_m = 2.18$, $N_p = 2.16$, $N_g - N_p = 0.02$, 2V = small to medium, $\rho < v$, very strong. Found at Terlingua, Texas. Very rare.

Mendipite ($Pb_3O_2Cl_2$) is orthorhombic with $a : b : c = 0.80 : 1 : ?$ Fibrous parallel to c; very perfect prismatic and very distinct 100 and 010 cleavages. H. = 2.5–3. G. = 7.0–7.1. F. = 1. Soluble in HNO_3. Acute bisectrix Z parallel to elongation, c; $X = a$. (+) 2V = nearly 90°, $\rho < v$ very strong; $N_g = 2.31$, $N_m = 2.27$, $N_p = 2.24$, $N_g - N_p = 0.07$. Colorless between parallel nicols at 0° and 90°, but gray at 45°. Mass color white, yellowish, bluish. Found with galena and pyrolusite. Very rare.

Laurionite $\{Pb(OH)Cl\}$ is orthorhombic with $a : b : c = 0.737 : 1 : 0.833$. Crystals prismatic with distinct 100 cleavage. H. = 3–3.5. G. = 6.24. F. = 1. Soluble in HNO_3. Loses water at 142° C. Optic plane is 010; $X = a$. (−)2V = 81° 32′. $N_g = 2.158$, $N_m = 2.116$, $N_p = 2.077$, $N_g - N_p = 0.081$ (Smith). $N_g - N_m = 0.040$, $N_m = 2.3 \pm$, $N_m - N_p = 0.058$, $N_g - N_p = 0.098$ (Césaro). Colorless between parallel nicols at 0° and 90°, but dark gray to bluish at 45°. Colorless in mass. Found in ancient lead slags at Laurium, Greece. Very rare.

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[8] *Tables Ann. Intern. Const.*, V, 1925.

ATACAMITE ORTH. $a:b:c = 0.661:1:0.753$ $Cu_2(OH)_3Cl$

PHYS. CHAR.—Crystals prismatic, vertically striated or tabular; also fibrous, or granular. Twinning on 110. Perfect 010 cleavage. H. = 3–3.5. G. = 3.78. F. = 3.5. Soluble in HCl.

OPT. PROP.—Optic plane is 100; X = b. (−) 2V = 75°, $\rho < v$ strong (2H = 94° Na; 99° Tl), $N_g = 1.880$ Tl, $N_m = 1.861$, $N_p = 1.831$, $N_g - N_p = 0.049$ Tl. Color bright green, streak apple green. Weakly pleochroic with X = pale green, Y = yellowish green, Z = grass green.

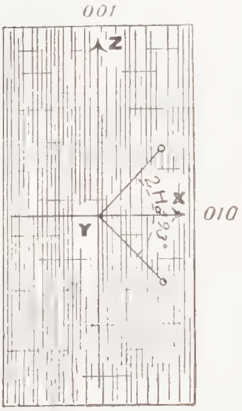

FIG. 24.—Optic orientation of atacamite.

ALTER.—Changes rather easily to malachite or chrysocolla.

OCCUR.—In oxide zone of copper deposits; also in sands and about hot springs on brass or copper.

DIAG.—Differs from malachite in having parallel extinction and weaker birefringence; the cleavage is parallel to the positive elongation and normal to the acute bisectrix X.

Kempite[9] ($MnCl_2 \cdot 3MnO_2 \cdot 3H_2O$) is orthorhombic with $a:b:c = 0.677:1:0.747$. Crystals prismatic. H. = 3.5. G. = 2.94. Soluble in HCl. Optic plane is 010; X = c. (−) 2V = moderate. $N_g = 1.698$, $N_m = 1.695$, $N_p = 1.684$, $N_g - N_p = 0.014$. Color emerald green. Found with pyrochroite, hausmannite, etc., in California. Very rare.

Paralaurionite $\{Pb(OH)Cl\}$ is monoclinic with $a:b:c = 2.704:1:1.802$, $\beta = 62° \ 47'$; the stability relations with laurionite are unknown. Crystals tabular parallel to 100 or prismatic parallel to b. Twinned on 100. Distinct basal cleavage. G. = 6.05. F. = 1. Soluble in HNO_3. Loses water at 180° C. Optic plane is 010; sections parallel to 100 show a double interference figure due to twinning. $N_m = 2.146$, $N_g - N_p$ = strong. Colorless to white, or violet (*rafaelite*) and pleochroic with Y = deep violet, X and Z = violet red to reddish yellow; the color may be very unequally distributed in zones parallel to the crystal edges. Found in the lead slags at Laurium and also (rafaelite) at a lead mine in Chile. Very rare.

Chloroxiphite[10] $\{2PbO \cdot Pb(OH)_2 \cdot CuCl_2\}$ is monoclinic with $\beta = 62\frac{3}{4}°$. Crystals elongated parallel to b, with perfect 001 and distinct 100 cleavages. H. = 2.5. G. = 6.76. F. = easy. Soluble in HNO_3. Optic plane normal to 010; X is near c. (−)2H = 80°. N_m = very high, $N_g - N_p$ = very strong. Color green with a = yellowish brown, b = Z = emerald green. Found in ore deposits. Very rare.

Terlinguaite (Hg_2OCl) is monoclinic with $a:b:c = 1.605:1:2.024$, $\beta = 74° \ 23'$. Crystals elongated parallel to b with perfect $\bar{1}01$ cleavege. H. = 2.5. G. = 8.7. Volatile. Optic plane normal to 010 and nearly normal to 100; $Y \wedge c = -7°$. In 010, extinction is at 39° to the $\bar{1}01$ cleavage. (−) 2V = 20° ± 2°, $\rho < v$ extreme. $N_g = 2.66$ Li, $N_m = 2.64$, $N_p = 2.35$, $N_g - N_p = 0.31$ Li. Color sulphur yellow, greenish, brown in a single crystal. Found at Terlingua, Texas, with eglestonite. Very rare.

Fiedlerite $\{Pb_3(OH)_2Cl_4\}$ is monoclinic with $a:b:c = 0.830:1:0.725$, $\beta = 77° \ 31'$. Crystals 100 tablets with distinct basal and 100 cleavages. H. = 3. G. = 5.88. Soluble in HNO_3. Optic plane normal to 010; X inclined 6° to a normal to 100. Biaxial negative. $N_g = 2.126(?)$, $N_m = 2.102$, $N_p = 1.816$, $N_g - N_p = 0.31 \pm$. Colorless. Found in lead slags at Laurium, Greece. Very rare.

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[9] A. F. Rogers: *Am. Jour. Sci.*, CCVIII, 1924, p. 145.

[10] L. J. Spencer and E. D. Mountain: *Mineral. Mag.*, XX, 1923, p. 75.

Daubréeite ($2Bi_2O_3 \cdot BiCl_3 \cdot 3H_2O?$) is a very finely crystalline earthy powder with H. = 2. G. = 6.4. F. = 1.5(?). Soluble in HCl. $N_m = 1.91$, $N_g - N_p = 0.01 \pm$. Color gray. Found at a mine in Bolivia. Very rare.

IV. OXIDES

THE oxides are here arranged, first in the order of increasing valence of the element combined with oxygen and second in the order of decreasing symmetry,—the anhydrous oxides being considered before the hydrous.

1. OXIDES OF MONOVALENT ELEMENTS

CUPRITE ISOMETRIC Cu_2O

PHYS. CHAR.—Crystals commonly octahedrons; also cubes and dodecahedrons, often much modified. Also capillary (*chalcotrichite*). Octahedral cleavage indistinct. H. = 3.5–4. G. = 5.85–6.15. Fusible, giving green flame color. Soluble in pure H_2SO_4.

OPT. PROP.—Isotropic with N = 2.849. Color red, usually cochineal red.

ALTER.—Malachite is the commonest product of alteration; also native copper, azurite, or chrysocolla.

OCCUR.—Usually in veins and confined to the upper oxidized portion. Also in cavities, or somewhat disseminated. Associated with other copper minerals.

DIAG.—Distinguished from other minerals of similar color by the isotropic character.

ICE HEXAGONAL $c = 1.62$ H_2O

PHYS. CHAR.—Complete crystals rare; often in skeleton *snow* crystals of hexagonal symmetry. Usually basal tablets, also granular massive. Basal gliding plane developed by pressure. H. = 1.5. G. = 0.918. Melts to *water* at 0° C. which has N = 1.333.

OPT. PROP.—Uniaxial positive. Refringence lower than that of almost any other mineral; birefringence weak. $N_o = 1.309$ Na, $N_e = 1.313$, $N_e - N_o = 0.004$. Colorless to white. In thick masses pale blue.

INVER.—Under high pressure other forms of H_2O are known; one is isotropic, and another is tetragonal; optic data are lacking.

OCCUR.—Abundant as a temporary constituent of surface rocks filling pores, fractures and cavities in winter in cold climates; also found occasionally at some depth below the surface. Also formed over lakes in crusts or layers composed of large acicular, irregularly arranged aggregates, or prisms arranged with vertical axes all normal to the surface of the water. In glaciers forming large masses whose texture is like that of granular limestone. In snow, crystals of skeletal hexagonal forms of great variety. In frost often dendritic, stellate, etc. In hail anhedral crystalline aggregates.

2. ANHYDROUS OXIDES OF DIVALENT ELEMENTS

Periclasite (*Periclase*—MgO) is isometric, in cubes, octahedrons, or grains with perfect cubic and indistinct octahedral cleavages. H. = 5.5–6. G. = 3.64–3.67. Fuses at 2800° C. Soluble without effervesence. Isotropic with N = 1.66 (nat. cryst.[1]); 1.730–1.739 (art. cryst.). Colorless to grayish or yellowish; brownish yellow, dark green; usually colorless in thin sections. Alters readily to hydromagnesite, to serpentine, or to brucite. Found in limestone modified by igneous action on Mte. Somma, in a manganese mine in Sweden, etc. Associated with monticellite, forsterite, spinel, magnesite, etc. Rare. Isotropic character, high relief, perfect cubic cleavage, and mineral associations are usually sufficient to identify the mineral.

Manganosite (MnO) is octahedral with cubic cleavage. H. = 5–6. G. = 5.18. F. = 7. Soluble in acid. N = 2.16 Li, 2.19 (green). Emerald green. Very rare.

Bunsenite (NiO) is octahedral. H. = 5.5. G. = 6.4 F. = 7. Soluble in acid. Isotropic with N = 2.23 Na. Green or brownish black. Very rare.

Lithargite (PbO) is tetragonal; crystals basal tablets with perfect prismatic cleavage. H. = 2. G. = 9.13. F. = 1.5. Soluble in HNO_3. Uniaxial negative with N_o = 2.64–2.665 Li, N_e = 2.535, $N_o - N_e$ = 0.13. Color yellowish red. Artificial "litharge" is a mixture of lithargite crystals bordering massicotite, from which they are doubtless derived. Rare natural crystals show a similar condition.

Zincite (ZnO) is hexagonal with $c = 1.622$; crystals rare, hemimorphic. Usually foliated massive, or granular. Perfect basal cleavage. H. = 4–4.5. G. = 5.43–5.7. F. = 7. Soluble in acids. Uniaxial positive, with N_o = 2.008, N_e = 2.029, $N_e - N_o$ = 0.021. Color deep red; rarely orange yellow. Streak orange yellow. In section deep red, not pleochroic. Atmospheric alteration produces smithsonite. Found with franklinite and willemite in New Jersey. Rare.

Massicotite (PbO) is orthorhombic with $a : b : c = 0.671 : 1 : 0.976$; crystals 100 tablets, massive crystalline; perfect 100 cleavage. Soft. G. = 9.29. F. = 1.5. Soluble in HNO_3. Axis Y (or X?) normal to 100. Optic angle very large, positive (negative in blue) with strong dispersion. N_g = 2.71 Li, N_m = 2.61, N_p = 2.51, $N_g - N_p$ = 0.20. Color yellow; streak lighter; pleochroic X (or Y?) = light sulphur yellow, Z = deep yellow. Found in the oxide zone of lead deposits. The crystals are commonly bordered by lithargite, probably the more stable form.

Montroydite (HgO) is orthorhombic with $a : b : c = 0.638 : 1 : 1.198$. Crystals prismatic with perfect 010 cleavage. H. = 2. Volatile. Soluble in HCl. Optic plane is 010 and Z is parallel to elongation (Larsen); optic plane is 100 and acute bisectrix is normal to 010 (Schaller). (+) 2V = large, N_g = 2.65, N_m = 2.50, N_p = 2.37, $N_g - N_p$ = 0.28. Color and streak orange red. Found in Texas. Very rare.

Tenorite (CuO) is triclinic with $a : b : c = 1.490 : 1 : 1.360$, $\alpha = 90°$, $\beta = 90°\ 32'$, $\gamma = 90°$. Crystals lath-shaped, twinned, pseudomonoclinic, 111 and $1\bar{1}1$ cleavages unequally distinct; basal cleavage distinct. H. = 3–4. G. = 6.45. F. = 3. Soluble in HCl. The acute bisectric (X?) is inclined to a normal to plates in which X′ makes an angle of 35° with elongation and twinning. N_m = extreme (nat. cryst.), 2.63 (red), 2.84 (white), 3.18 (blue) (art. cryst.), $N_g - N_p$ = strong. Color and streak black to iron gray. Absorption very strong with $X < Z$ and X = light brown, Z = nearly opaque. Found at Vesuvius, and uncommon in ore deposits.

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[1] Lévy and Lacroix: *Tabl. Min. Roches*, 1889. This is the only known measure on natural crystals; apparently it is too low.

3. HYDROUS OXIDES OF DIVALENT ELEMENTS

BRUCITE TRIGONAL $c = 1.521$ $Mg(OH)_2$

PHYS. CHAR.—Crystals basal plates; many samples foliated massive, some fibrous. Micaceous basal cleavage with flexible and sectile lamellæ. H. = 2.5. G. = 2.4. F. = 7. Soluble in HCl.

OPT. PROP.—Uniaxial positive; fibrous types distinctly biaxial, the fibers being elongated parallel to a diagonal of the base with X parallel to the elongation.

	Artini[2]	
$N_e = 1.5815$ (Li)	......	1.5949 (violet)
$N_o = 1.5617$	1.564	1.5794
$N_e - N_o = 0.0198$		0.0155

Color white, grayish, greenish. Colorless in section.

ALTER.—Brucite alters to hydromagnesite; rarely to serpentine.

OCCUR.—Common in serpentine; found in anamorphosed limestones, and in slates and schists.

DIAG.—Brucite has better cleavage than alunite and flexible lamellæ; also wholly different occurrence and associations; it differs from talc, muscovite and gypsum in being uniaxial and positive, and from hydromagnesite and white chlorite (leuchtenbergite) in having stronger birefringence.

Pyrochroite $\{Mn(OH)_2\}$ is trigonal with $c = 1.4$; crystals platy, with perfect basal cleavage. H. = 2.5. G. = 3.26. F. = 7. Soluble in HCl. Uniaxial negative, or slightly biaxial, with $N_o = 1.723$, $N_e = 1.681$, $N_o - N_e = 0.042$ (Sjögren[3]); $N_o = 1.733$, $N_o - N_e = 0.04$ (Rogers[4]). Colorless to brown or yellowish red and pleochroic with $X < Z$. Associated with hausmannite; rare.

4. ANHYDROUS OXIDES OF TRIVALENT ELEMENTS

Senarmontite (Sb_2O_3) is isometric; crystals octahedral, with octahedral cleavage only in traces. H. = 2. G. = 5.2. F. = 1.5, volatile. Soluble in HCl. Isotropic. N = 2.087 Na. Also distinctly anisotropic in twinned areas as in boracite or the hexoctahedral type of garnet, perhaps due to inversion; ascribed to strain by Brauns. When anisotropic the birefringence is weak and the optic angle large. Colorless. Found as an oxidation product of stibnite in ore deposits.

Arsenolite (As_2O_3) is also isometric, octahedral, or fibrous massive. H. = 1.5. G. = 3.71. F. = 1, volatile. Slightly soluble in H_2O. Isotropic with N = 1.755 Na. May be biaxial. White or stained. An oxidation product of arsenical ores; a smelter fume product; formed about burning coal mines.

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[2] *Min. Abst.*, II, 1924, p. 240.

[3] *Geol. För. Förh.*, XXVII, 1905, p. 37.

[4] *Am. Jour. Sci.*, CXCVIII, 1919, p. 443.

Bismite $\{Bi_2O_3$ (with $3H_2O$?)$\}$ is trigonal with $c = 0.578$. Crystals basal plates with perfect basal cleavage. Soft. G. = 4.36. Soluble in HNO_3. Uniaxial negative with $N_o = 2.00$, $N_e = 1.82$, $N_o - N_e = 0.18$. Color white. Found in ore deposits. Rare.

CORUNDUM Trigonal $c = 1.363$ Al_2O_3

Phys. Char.—Crystals usually hexagonal, pyramid-like forms and the base. Angles often rounded. Twinning plane the rhombohedral face $10\bar{1}1$; sometimes penetration twins, sometimes polysynthetic. Cleavages absent; but parting parallel to 0001 is sometimes perfect, though interrupted. Parting due to twinning parallel to $10\bar{1}1$ sometimes also present. H. = 9. G. = 3.95–4.10. Fuses at 2050° C. Insoluble in acids.

Opt. Prop.—Uniaxial and negative, but often showing optic anomalies consisting of biaxial crystals or parts of crystals. The optic angle is usually small ($2E = 10°–12°$), but sometimes larger ($2E = 58°$). The biaxial character is distinct in crystals from near Bozeman, Montana. Birefringence weak; refringence high, increasing in red corundum with depth of color.

	Colorless	Blue (*Sapphire*)	Light to dark red (*Ruby*)
$N_o =$	1.7681–1.7695 Na	1.7687 Na	1.7671–1.7717 Na
$N_e =$	1.7599–1.7613	1.7605	1.7594–1.7632
$N_o - N_e =$	0.0082–0.0082	0.0082	0.0077–0.0085

Ignited alumina hydrogel has N = 1.68.

Color blue, red, yellow, brown, gray, nearly white. Pleochroism very distinct in deeply colored varieties; ordinary gray corundum is colorless in thin section. Usually blue or gray in rocks. In thick plates X = green or bluish or colorless, Z = blue.

Alter.—Alteration products include muscovite, spinel, cyanite, sillimanite, corundophilite, etc.

Occur.—Usually found in crystalline metamorphic rocks such as marble, mica or chlorite slate, gneiss, etc. Also found in eruptive rocks and in rocks metamorphosed locally by eruptives. Also in stream gravels.

Diag. Distinguished by very high relief and weak birefringence; also by its form, hardness, specific gravity, and insolubility.

HEMATITE Trigonal $c = 1.359$ Fe_2O_3

Phys. Char.—Crystals of varied habit; rhombohedral faces usually prominent with or without the base. No cleavage, but sometimes basal or rhombohedral parting, the latter due to polysynthetic twinning. H. = 5. G. = 5.2. Infusible, but becomes magnetic in reducing flame. Soluble in HCl.

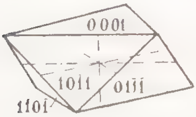

Fig. 25.—A crystal habit of hematite.

Opt. Prop. Uniaxial negative. The refringence is very high and the birefringence very strong.

	Artificial		Natural		
N_o	> 2.95 (700 $\mu\mu$)	3.01 Li	3.05 (Red)	3.042 Li(C)	3.22 Na
N_e	$= 2.74$ (700 $\mu\mu$)	2.94	2.87	2.797	2.94
$N_o - N_e$	$= 0.21+$	0.07	0.18	0.245	0.28

Hematite said to contain 17.8 per cent FeO (or 50 per cent Fe_3O_4) in crystal solution[5] is said to have $N_e = 2.71$, and (with 16.1 FeO), $N_o - N_e > 0.16$.

Most hematite, if coarse grained, produces marked rotation of the plane of polarization of reflected light.

Color of crystals steel gray to iron black with good to brilliant luster. Earthy varieties red. Streak red. Opaque except in very thin scales which are blood red and slightly pleochroic, as follows: Z = brownish red, X = yellowish red.

Inver.—Hematite shows a sharp inversion point at 678° C., but the characteristics of the high temperature form are unknown. Another inversion is reported at −40° C.

Alter.—Hematite is a common alteration product, but it may itself alter to magnetite, siderite, limonite, pyrite, etc.

Occur.—Hematite often occurs as microscopic inclusions and alteration products in many minerals and rocks, coloring them red. It is also found as a product of fumaroles in large crystals in eruptive rocks. It occurs as a product of contact metamorphism, and in various crystalline schists. It is common in many mineral, as well as in metalliferous, veins. Finally, it is very abundant in some ordinary sedimentary rocks. It is one of the most widely disseminated of minerals.

Diag.—Distinguished from magnetite and ilmenite by the deep red color of thin scales or of powder; but hematite in crystals or in very compact masses in thin section is opaque and black in reflected light. Cinnabarite has the color of massive hematite, but it has perfect hexagonal prismatic cleavage, is positive, and is of very restricted occurrence. Moreover, it has much higher specific gravity (8-8.2) than hematite.

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[5] R. B. Sosman and J. C. Hostetter: *Jour. Amer. Chem. Soc.*, XXXVIII, 1916, p. 807.

Hydrohematite (*Turgite*—$Fe_2O_3 \cdot nH_2O$) is probably an intimate mixture of goethite and hematite, with the latter dominant in most cases. G. = 4.5–5. Apparently uniaxial with negative sign and $N_o = 2.5–2.7$, $N_e = 2.3–2.6$, $N_o - N_e = 0.1–0.2$. Always fibrous, with parallel extinction and negative elongation. Color red in mass; lighter than hematite in powdered form, and of orange tint. Pseudomorphous hydrohematite may have positive elongation or inclined extinction or both.

Valentinite (Sb_2O_3) is orthorhombic with $a : b : c = 0.394 : 1 : 0.434$; crystals prismatic or tabular parallel to 010, or elongated parallel to a, with perfect 010 cleavage. H. = 2.5–3. G. = 5.76. Easily fusible, and somewhat volatile. Soluble in HCl. Acute bisectrix X is normal to 100; the optic plane is 001 in red and yellow light, and 010 in green and blue light. When heated to 75° C. the optic angle in red light decreases somewhat, and in blue light increases. (−) 2V = very small (dispersion marked). $N_g = 2.35$, $N_m = 2.35$, $N_p = 2.18$, $N_g - N_p = 0.17$. Color white, rarely gray, pink, brownish. An oxidation product of antimony ores, often mixed with cervantite and stibiconite.

Claudétite (As_2O_3) is related to valentinite, but is monoclinic with $a : b : c = 0.404 : 1 : 0.345$, $\beta = 86° 3'$. Crystals prismatic or tabular (010). Twinning common on 100, of penetration type. Perfect 010 and distinct 110 cleavages; 010 laminæ flexible. H. = 2.5. G. = 3.85–4.15. Volatile at 1. Slightly soluble in H_2O. Optic plane is 010; $Z \wedge c = +6°$. (+) 2V = 58°, $\rho > v$ strong. $N_g = 2.01$, $N_m = 1.92$, $N_p = 1.87$, $N_g - N_p = 0.14$. Colorless to white. An oxidation product of arsenical ores, notably arsenopyrite; also formed about burning coal mines, and in smelter fumes.

5. HYDROUS OXIDES OF TRIVALENT ELEMENTS

DIASPORE GROUP

The diaspore group includes orthorhombic hydroxides of trivalent metals. The axial ratios vary so much that crystal solution is probably possible only to a very limited extent. The following minerals are included:

Diasporite	$a : b : c = 0.937 : 1 : 0.604$	$Al_2O_3 \cdot H_2O$	or	$AlO(OH)$
Goethite	$a : b : c = 0.918 : 1 : 0.607$	$Fe_2O_3 \cdot H_2O$	or	$FeO(OH)$
Manganite	$a : b : c = 0.844 : 1 : 0.545$	$Mn_2O_3 \cdot H_2O$	or	$MnO(OH)$

DIASPORITE (*Diaspore*) ORTH. $a : b : c = 0.937 : 1 : 0.604$ $Al_2O_3 \cdot H_2O$

PHYS. CHAR.—Crystals prismatic, usually flattened parallel to 010; with perfect 010 and distinct 210 cleavages. H. = 6.5–7. G. = 3.4. F. = 7. Insoluble in acid; soluble in H_2SO_4 after calcination. Soluble in hot NaOH, from which gibbsite crystallizes on cooling.

Opt. Prop.—The optic plane is 010 and $Z = a$. $(+)2V = 84°\ 20'$, $\rho < v$, weak. $N_g = 1.750$, $N_m = 1.722$, $N_p = 1.702$, $N_g - N_p = 0.048$.

Color white, gray, brown, violet, etc. Usually colorless in section, but also X = dark violet or reddish brown, Z = yellowish white. In thick sections still other colors observed, notably blue and green.

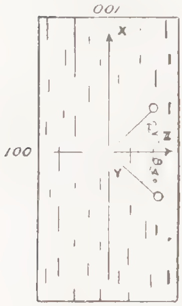


Fig. 26.—Optic orientation of diasporite.

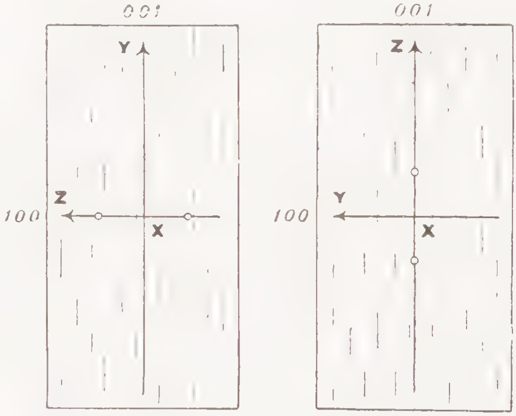
Occur.—Often associated with corundum; also found in volcanic rocks with alunite; also in various schists. Common in French bauxite deposits.

Diag.—Among lamellar minerals distinguished by the position of the optic plane parallel to the cleavage and by the strong birefringence; also by insolubility, hardness and specific gravity.

GOETHITE Orthorhombic $a : b : c = 0.918 : 1 : 0.602$ $Fe_2O_3 \cdot H_2O$

Phys. Char.—Crystals vertically striated prisms; also scaly or tabular parallel to 010, or, rarely, 100; perfect 010 cleavage. H. = 5–5.5. G. = 4.28 (pure); 4.0–4.4 (natural). F. = 5.5. Soluble in HCl.

Opt. Prop.—The pure mineral[6] has extreme dispersion of optic axes, so that the optic plane is 100 for red and 001 for yellow, green and blue in the common condition, and the mineral is uniaxial for light of wave-length 610–620 μμ. The acute bisectrix, normal to 010, is negative for all colors, giving positive elongation of plates. $N_g = 2.400$ Na, $N_m = 2.394$, $N_p = 2.260$, $N_g - N_p = 0.140$. Increase of temperature causes the optic angle in 001 to decrease rapidly,



Figs. 27, 28.—Optic orientation of goethite.

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[6] E. Posnjak and H. E. Merwin: *Am. Jour. Sci.*, CXCVII, 1919, p. 311.

become zero, and open again in 100. The mineral is often fibrous and impure with adsorbed water, etc., and then: $N_g = 2.11–2.35 +$, $N_m = 2.10–2.35$, $N_p = 2.05–2.21$, $N_g - N_p = 0.06–0.14$.

Color brown, yellowish, reddish. Streak yellow. In thin section pleochroism variable with $a > c > b$ and X = clear yellow to brown, Y = brown yellow, Z = orange yellow. Gray in vertical reflected light.

Occur.—Much of the so-called "limonite" iron ore is goethite; also found as inclusions and replacements in quartz and feldspars.

Diag. Distinguished from limonite by crystallization and anisotropic character; from lepidocrocite by abnormally strong dispersion and only one good cleavage. Hematite is hexagonal and uniaxial.

Limonite ($Fe_2O_3 \cdot nH_2O$) is apparently amorphous with no cleavage. H. = 4 ±. G. = 3.8 ±. F. = 7. Soluble in HCl. Isotropic with N. = 2.0–2.1. A *red* isotropic substance (limonite with very little water?) has N = 2.2–2.3. Some limonite shows stages of gradual change to goethite, and the isotropic condition is really crystalline, and only coarser crystallization is necessary to change the material to goethite. Such material shows indefinite and variable birefringence, usually not strong, but reaching 0.04 in some cases. The X-ray patterns of such material show it to be identical with goethite. Limonite is yellow, brown, brownish black; it may be iridescent on the surface. Streak yellowish brown. Translucent yellow (to brownish) in thin section or fine powder. Limonite is very common as an alteration product of ferriferous minerals. It is found in all kinds of rocks. It is formed in the upper part of nearly all veins, and is deposited by some hot springs, occasionally in sufficient abundance to serve as an iron ore. Common in sediments, forming some important ores. Also forms in swamps as "bog iron ore." Common in submicroscopic particles staining other minerals.

Manganite ($Mn_2O_3 \cdot H_2O$) is orthorhombic with $a : b : c = 0.844 : 1 : 0.545$. Crystals usually have many faces; striations parallel to b common. Twinning on 011. Perfect 010 and 110 cleavages. H. = 4. G. = 4.2–4.4. F. = 7. Soluble in HCl. Nearly opaque; optic plane is 010; Z parallel to elongation or c (Larsen). $Z \wedge c = 0°–4°$, $\rho < v$ (Mügge[7]). (+) 2V = small, with strong dispersion, $\rho > v$. $N_g = 2.53$ Li, $N_m = 2.25$, $N_p = 2.25$ (2.23), $N_g - N_p = 0.28$. Color steel gray to iron black. Streak dark reddish brown. Pleochroic in thin section, red brown to brownish yellow, with $X < Z$. Grayish white in vertical reflected light. Strongly anisotropic in reflected light, producing a rotation[8] of the plane of polarization amounting to $5''$. Alters readily without loss of form or luster to pyrolusite. Found in metalliferous veins and rarely in sedimentary rocks. Among manganese minerals manganite is distinguished by its crystal form, its easy cleavage, its frequent fibrous or lamellar state, and its streak. The color differs from that of goethite.

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[7] *Cent. Min.*, 1922, p. 1.

[8] E. Sampson: *Econ. Geol.*, XVIII, 1923, p. 775.

Lepidocrocite ($Fe_2O_3 \cdot H_2O$) is orthorhombic; $a : b : c = 0.434 : 1 : 0.64$. Crystals scaly parallel to 010 which is direction of perfect cleavage; 001 cleavage less perfect; 100 cleavage good. G. = 4.09. The optic plane is 100 and Z = *c*. (+) 2V = 83° (dispersion slight); $N_g = 2.51$, $N_m = 2.20$, $N_p = 1.94$, $N_g - N_p = 0.57$. Color blood red; streak dull orange; pleochroic in thick sections with X = clear yellow, Y = orange yellow to red-orange, Z = brownish yellow to orange-red, and X < Y < Z. Found in iron ore deposits with limonite. Differs from goethite in having weak dispersion, and also (Lacroix) in having maximum absorption parallel to the elongation.

GIBBSITE (*Hydrargillite*) MONOCLINIC $Al_2O_3 \cdot 3H_2O$

$$a : b : c = 1.709 : 1 : 1.918,\ \beta = 85° 29'$$

PHYS. CHAR.—Crystals uncommon, like hexagonal basal tablets; often fine lamellar; also in concretions or crusts. Basal cleavage micaceous, giving slightly flexible lamellæ. Percussion figures similar to those of the micas producing lines normal to sides of the hexagon. Twinning common on 001 and on 130; other types not rare; twinning often multiple and complex as in plagioclase. H.= 3. G. = 2.35. F. = 7. Soluble in H_2SO_4. Soluble in hot NaOH from which it recrystallizes on cooling.

OPT. PROP.—The variation in optic properties in different samples is perhaps due to the effects of temperature, since heat has a marked effect on the optic angle and may change the optic orientation. In most crystals the optic plane is normal to 010 and the positive acute bisectrix makes an angle of 21° to 44° with *c*. The optic angle decreases with rise of temperature, becoming 0° at about 27° C. (for blue); above that temperature, the optic plane is parallel to 010. Upon cooling the changes are reversed. In nature the mineral occurs with the optic angle in any of the positions thus produced by heat. The optic angle is always small and may be 0°.

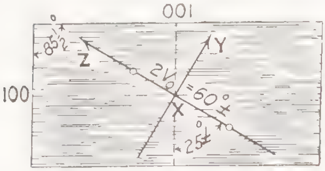

FIG. 29.—Optic orientation of gibbsite.

$$(+)2V = 0°–40° \pm \ \rho > v \text{ strong (normal to 010), or}$$

$$(+)2V = 0°–40° \pm \ \rho < v \text{ strong (in 010)}$$

$N_g = 1.589\ (1.585)$ $N_m = 1.567$ $N_p = 1.567$ $N_g - N_p = 0.019–0.022$

$N_g = 1.576$ $N_m = 1.554$ $N_p = 1.554$ $N_g - N_p = 0.222$

Color white, grayish, greenish; colorless in thin section.

Occur.—Abundant in bauxite deposits in America. Often associated with corundum; a common decomposition product of feldspars.

Diag.—Distinguished from kaolinite by stronger birefringence, from muscovite by optic sign and inclined extinction, from brucite and wavellite by inclined extinction and chemical reactions.

Bauxite ($Al_2O_3 \cdot nH_2O$) is apparently amorphous hydrated alumina, rarely pure, but mixed with limonite, silica, aluminum silicate, etc. It is typically concretionary and probably always colloidal. G. = about 2.55, N = 1.56 ± to 1.61±. After ignition N = 1.68. Color gray, yellow, white, brown, varying with the tenor of limonite, and grading into iron ore. It is the chief aluminum ore. It may be distinguished from clay since it does not make a paste with water and is attacked by alkalies.

Sassolite ($B_2O_3 \cdot 3H_2O$) is triclinic with $a : b : c = 1.733 : 1 : 0.923$, and $\alpha = 92° 30'$, $\beta = 104° 25'$, $\gamma = 89° 49'$. Crystals basal plates, pseudohexagonal; scaly, stalactitic; twinning about c; perfect basal cleavage. H. = 1. G. = 1.48. F. = 0.5. Soluble in H_2O. Optic plane nearly parallel to axis a, and X nearly normal to 001. Extinction angle on 100 to c is 12° to 13° (Haushofer), 0° to 4° (d'Achiardi); on 001 to a is 2.5° to 20°; on 110 to c is 12° to 13°. Basal plates weakly birefringent, in part nearly uniaxial. (−) 2E = 8°–12° (dispersion not visible). $N_g = 1.459$, $N_m = 1.456$, $N_p = 1.340$, $N_g - N_p = 0.119$. Color white or grayish. Found in Tuscan lagoons; also about volcanoes. Very rare. Fused sassolite (B_2O_3) has N = 1.4637 D.

6. ANHYDROUS OXIDES OF TETRAVALENT ELEMENTS

Ulrichite (UO_2?) is described with uraninite; see p. 69.

Thorianite $\{(Th,U)O_2\}$ is isometric; ThO_2 varies from 59 to 93 per cent and UO_2 from 32 to 5 per cent. Crystals cubic. H. = 6.5. G. = 9.32. F. = 7. Soluble in HNO_3. Remarkably radioactive. Isotropic and nearly opaque with N = 2.20. Color black. Reddish brown in section. Found in gem washings and pegmatite in Ceylon, etc. Very rare.

RUTILE GROUP

The minerals of the rutile group are tetragonal and have closely similar forms and the same twinning laws. Their optic properties are also very similar; all are uniaxial with high refringence and strong birefringence; all except plattnerite are positive. Zircon and thorite are sometimes classed as silicates, but recent X-ray studies make it probable that they are double oxides. The following minerals may be referred to the group.

Zircon	$c = 0.6391$	$ZrO_2 \cdot SiO_2$
Thorite	$c = 0.6402$	$ThO_2 \cdot SiO_2$
Rutile	$c = 0.6439$	TiO_2
Cassiterite	$c = 0.6726$	SnO_2
Plattnerite	$c = 0.6764$	PbO_2

ZIRCON TETRAGONAL $c = 0.6404$ $ZrO_2 \cdot SiO_2$

PHYS. CHAR.—Commonly in square prisms, vertically elongated and terminated by unit pyramids. Always crystallized. Twinning on 101 uncommon. Prismatic cleavage rare. G. = 4.68–4.70. H. = 7.5. Infusible. Slowly attacked when in fine powder by concentrated H_2SO_4.

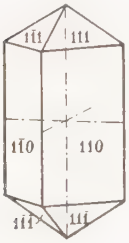

FIG. 30.—A crystal habit of zircon.

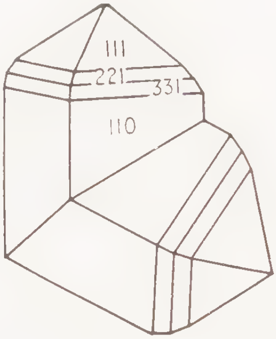

FIG. 31.—A geniculated twin of zircon.

OPT. PROP.—Uniaxial positive with $N_o = 1.923$ to 1.960, $N_e = 1.968$ to 2.015, $N_e - N_o = 0.045$ to 0.058. Birefringence increases with decrease in wave length. $N_o - N'_e$ on the cleavage[9] = 0.019–0.028. Zircon with 10 per cent ZrO_2 in crystal solution in $ZrSiO_4$ has G. = 4.58, $N_o = 1.925$, $N_e = 1.985$, $N_e - N_o = 0.060$. Contracts on heating to 950° C. so that G. = 4.68.

Color yellow, brown, gray, rarely green or colorless. In thin section colorless to pale brown or gray. Pleochroism invisible in thin section, very weak in sections more than 1 mm. thick, with maximum absorption parallel to Z.

Optical anomalies are unknown in the microscopic crystals, but appear in large crystals. Zonal structure is frequent in such cases. The mineral then appears biaxial and positive, with a small optic angle (2V = 10°; $N_g = 1.9820$, $N_m = 1.9277$, $N_p = 1.9272$;

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[9] H. Buttgenbach: *Minéraux et Roches*, 1916, p. 508.

$N_g - N_p = 0.0548$ in olive green *beccarite* from Ceylon), the bisectrix being parallel to the quaternary axis. Mallard considers the common tetragonal symmetry to be due to twinning, often submicroscopic, of monoclinic individuals. The optic anomalies are perhaps due to alteration, being found especially in partly altered zircon.

ALTER.—Zircon resists alteration to a marked degree; but in some cases it becomes hydrous, and then the specific gravity falls rapidly from 4.7 to about 4.1, and the hardness decreases from 7.5 to about 3; at the same time the refringence decreases and the birefringence falls even more rapidly to a value of zero to 0.010 ± in *malacon* with 3–10 per cent H_2O. When the process continues further iron is often introduced as well as water. The following data, illustrate this process (values for zircon of density 4.33 are only approximate).

G	N	N_e	N_o	$N_e - N_o$
4.7		1.9682	1.9239	0.044
4.33	1.882			0.034
4.21		1.86	1.85	0.010
4.06	1.826			very weak

OCCUR.—Zircon is very widely distributed as an accessory constituent of igneous rocks of all kinds, but it is especially common in syenite, granite, nepheline syenite, and diorite. It appears very sparingly in gabbro, peridotite, and theralite. It is apparently more abundant in plutonic than in volcanic rocks. It is also found in many kinds of metamorphic rocks, and by disintegration it reaches the sands and sediments.

It is one of the very earliest minerals to crystallize from a magma, and therefore it is found enclosed in many of the other rock minerals. When enclosed by micas (especially biotite) chlorite, cordierite, andalusite, sometimes amphiboles or pyroxenes, it is surrounded by intense pleochroic halos.

DIAG.—Zircon may be distinguished from cassiterite by much weaker birefringence, the mode of occurrence, and chemical reactions; from xenotimite, by higher refringence, less perfect prismatic cleavage, greater hardness, and chemical reactions; from thorite by much stronger birefringence, greater hardness, and insolubility in HCl.

Thorite ($ThO_2 \cdot SiO_2$) is tetragonal with $c = 0.6402$; crystals square prisms with pyramidal terminations. Forms like zircon. Distinct 110 cleavage. H. = 4.5–5.

G. = 5.2–5.4. Infusible. Gelatinizes before, but not after, calcination. Uniaxial positive with $N_o = 1.8$; $N_e - N_o = 0.01$; commonly isotropic from hydration and then N = 1.68 to 1.72 +. After ignition N = 1.78 ±. Color orange yellow, brownish yellow, brownish black. Streak light orange to dark brown. Very rarely found unaltered. Upon alteration the specific gravity decreases to 4.8 or even 4.4, and the mineral becomes hydrous, and apparently isotropic. Found in syenite in Scandinavia; also in the Champlain iron district of northern New York. Rare. Usually apparently amorphous and isotropic from alteration. Contains thoria.

Auerlite ($ThO_2 \cdot SiO_2, \frac{1}{2}P_2O_5 \cdot 2H_2O$) is tetragonal and isomorphous with thorite; twinning on 111. H. = 2.5–3. G. = 4.1–4.8. F. = 7. Uniaxial positive with $N_o = 1.65$, $N_e - N_o = 0.01$. Color yellow. Found in gneiss. Very rare. Auerlite is here regarded as a variety of thorite with some Si atoms replaced by P atoms.

Mackintoshite ($3ThO_2 \cdot 3SiO_2 \cdot UO_2 \cdot 3H_2O$?) is tetragonal like thorite. H. = 5.5. G. = 5.44. F. = 7. Slowly soluble in acid. Isotropic (probably through alteration) with N = 1.77. Color black; in section nearly colorless, but cloudy. Very rare.

Pilbarite is perhaps an alteration product of a uranium-bearing thorite; it is about $ThO_2 \cdot UO_2 \cdot 2SiO_2 \cdot PbO \cdot 4H_2O$. H. = 3. G. = 4.6 ±. Soluble in acid. Isotropic with N = 1.74 ±. Color canary yellow. Found in ore deposits. Very rare.

RUTILE TETRAGONAL $c = 0.6441$ TiO_2

COMP.—Rutile often contains some $FeTiO_3$ (in crystal solution in $TiTiO_4$?) which increases the density and doubtless also the indices. The density of pure $TiTiO_4$ is 4.23; with 50 (volume) per cent of $FeTiO_3$ the density[10] is 4.50. The $FeTiO_3$ is considered admixed ilmenite by Watson.[11]

PHYS. CHAR.—Crystals nearly always elongated parallel to c, sometimes finely fibrous, and vertically striated. Twinning on 101 frequent in macroscopic crystals; this type is known as geniculated twinning when composed of two parts; when composed of several parts it may be arranged in a cycle of six or eight, or it may form lamellæ visible microscopically in basal sections. Twinning also on 301, rare in large crystals, but commonly found of microscopic size. Twinning on 902 is always polysynthetic and accompanied by parting planes. The reticulated groups in *sagenite*, etc., are usually due to a combination of these two twinning laws. Good prismatic cleavage. H. = 6–6.5. G. = 4.18–4.25. Infusible. Insoluble.

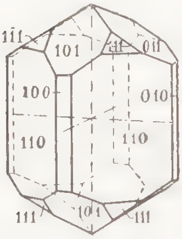

FIG. 32.—A crystal habit of rutile.

OPT. PROP.—Uniaxial positive, with the highest refringence found in any rock-forming mineral.

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[10] E. F. Holden: *Am. Mineral.*, VI, 1921, p. 100.

[11] *Am. Mineral.*, VII, 1922, p. 185.

$N_e =$	2.8415–2.8514 Li	2.889–2.903 Na	2.9817 Tl
$N_o =$	2.5671–2.5752	2.603–2.616	2.6725
$N_e - N_o =$	0.2744–0.2762	0.286–0.287	0.3092

Color red, reddish brown, brownish black, yellow, bluish, violet, rarely green. Streak pale brown. In thin section pleochroism often not noticeable. Sometimes it is distinct with X = yellow, or brownish red in a thick section, and Z = brownish yellow to yellowish green, or dark blood red to black in a thick section. Grayish white in vertical reflected light.

Rutile sometimes shows optic anomalies consisting of biaxial twinning bands crossing basal sections of the uniaxial mineral; in these bands the optic plane is parallel to 110; the biaxial appearance is probably due to the combined effect of several twinning lamellæ at various angles.

Alter.—Rutile is relatively a very stable mineral; nevertheless, it is found to undergo various modifications in nature. One of the most common is the change to ilmenite. This is a process all of whose stages can be observed in various sections; the ilmenite forms about the borders and then along the cleavage lines of the rutile. In other cases rutile may be changed into titanite—a process which is sometimes reversed.

Inver.—Rutile is the stable form of TiO_2 at high temperatures, and perhaps the most stable at all temperatures. Its solubility in crystallized silicates increases with rising temperature.

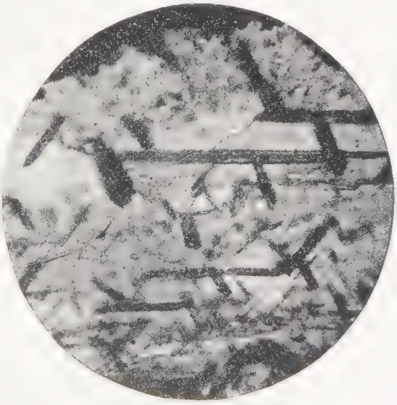

Fig. 33.—Photomicrograph of rutile in a rock section.

Occur.—Rutile is more widely distributed as a microscopic element of various rocks than as crystals of megascopic size. It is found in igneous rocks very widely distributed, but in such rocks it is much more commonly a result of alteration than a product of magmatic crystallization. It is very abundant in many metamorphic rocks, such as amphibolites, pyroxenites, gneiss, eclogites, etc. It is likewise common in some simple sedimentary rocks, and in rocks produced by contact or regional metamorphism from these. Finally, it is found in many veins, both metalliferous and non-metalliferous. It is then commonly associated with quartz, calcite, topaz, pyrite, sphalerite, etc.

Diag.—Distinguished by reddish brown to yellow color, very high relief and extremely strong birefringence. Also characterized by brilliant luster, distinct tetragonal cleavages, and high density.

CASSITERITE Tetragonal $c = 0.672$ SnO_2

Phys. Char.—In short prismatic or pyramidal crystals, or in anhedra. Prismatic cleavage distinct. Twinning as with rutile. H. = 6–7. G. = 6.8–7.1.

Opt. Prop.—Uniaxial positive with $N_o = 1.997$, $N_e = 2.093$, $N_e - N_o = 0.097$. Also $N_o = 1.9983$ (He yellow), $N_e = 2.0945$, $N_e - N_o = 0.0962$. Also sometimes biaxial of small optic angle. Refringence increases and birefringence decreases with decrease of wave length.

Color brown to black; also red, gray, yellow, white to almost colorless. Color sometimes irregularly distributed or in bands or zones. Luster adamantine. In thin section colorless, yellowish, brown, or reddish. In rare cases pleochroic with: X(O) = carmine, deep red, brownish yellow, black, pale brown; Z(E) = colorless, green, golden yellow, iron gray, deep wine-red. Gray in vertical reflected light.

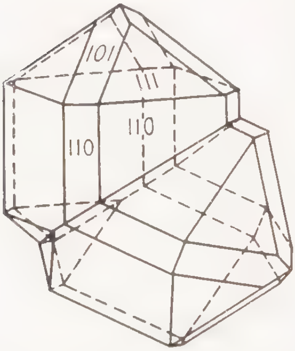

Fig. 34.—A geniculated twin of cassiterite.

Inver.—Hexagonal and orthorhombic forms of SnO_2 have been made artificially, but the stability relations are unknown.

Occur.—Usually produced by the action of mineralizers from acid granites in veins or in pegmatite. Also found in sulphide veins and in stream gravels.

Diag. Distinguished from rutile by its less extreme birefringence which produces bright colors, instead of the indefinite grays of the higher orders, in very thin sections.

Plattnerite (PbO_2) occurs rarely in crystals of prismatic habit; usually massive, sometimes globular. Cleavage unknown. H. = 5–5.5. G. = 8.5. Fusible at 2. Soluble. Uniaxial negative with $N_o = 2.3 \pm$ Li. Also biaxial in twinned pseudotetragonal groups. Translucent to nearly opaque. Color iron black. Streak chestnut brown. Found in lead mines in Scotland and Coeur d'Alène district, Idaho. Rare. Distinguished from other minerals of the rutile group by mode of occurrence and negative sign. An artificial hydrated lead dioxide [12] is reported to have $N = 2.229$ D.

OCTAHEDRITE (*Anatase*) TETRAGONAL $c = 1.777$ TiO_2

PHYS. CHAR.—Commonly octahedral in aspect; also tabular or prismatic. Distinct basal and pyramidal cleavage. H. = 5.5–6. G. = 3.82–3.95. F. = 7. Insoluble.

OPT. PROP.—Uniaxial negative with extreme refringence. Indices vary, probably with tenor of iron. An abnormal biaxial condition is not rare.

Taubert [13]	Others
$N_o = 2.5603$ (D)	2.534–2.564 Na
$N_e = 2.4877$ (D)	2.489–2.497 Na
$N_o - N_e = 0.0726$ (D)	0.038–0.073 Na

$N_o - N'_c$ on the pyramidal cleavage [14] $= 0.053$.

Color brown, yellow, blue, black. In section lighter shades of these colors, sometimes irregularly or zonally distributed. Pleochroism weak in most cases with X = yellow to light brown or blue, Z = orange to brown or deep blue and $X < Z$. But Brazilian octahedrite is reported to show $X > Z$.

INVER.—Artificially octahedrite is produced only at low temperature, brookite at intermediate and rutile at high temperatures. But rutile forms also at low temperatures in nature.

OCCUR.—Rare in igneous rocks and schists, probably an alteration product.

DIAG.—Easily distinguished from rutile and brookite by its uniaxial negative character. The crystal form is also characteristic, being usually octahedral in aspect.

CRISTOBALITE TETRAGONAL? (Pseudoisometric) SiO_2

PHYS. CHAR.—Crystals octahedral or skeletal; twinning on 111. H. = 6–7. G. = 2.27. Fuses at 1710° ± 10° C. Insoluble.

OPT. PROP.—Strictly isotropic (and isometric) above 200° to 275° C.; below that temperature shows complicated twinning of weakly birefringent uniaxial form, probably tetragonal; though it may appear biaxial. Also, by lack of inversion, crystals or parts of crystals may be isotropic. The isotropic form has been called *metacristobalite* and has $N = 1.486$. The uniaxial form is negative with low refringence:

$$N_o = 1.487 \quad N_e = 1.484 \quad N_o - N_e = 0.003$$

Colorless in section. Milky white in mass. Luster vitreous.

INVER.—Cristobalite is the stable form of silica above 1470° C. Below that temperature it is unstable, but may persist as a metastable form for long periods. The high temperature isometric form (α-cristobalite) inverts with 28 per cent increase of volume to a tetragonal (?) form (β-cristobalite) at temperatures which show an unexplained variation from 275° to 220° C. on cooling, and from 198° to 240° C. on heating. For a given crystal the inversion is at a fixed temperature, but for other crystals it seems to depend upon previous heat treatment.

OCCUR.—In cavities in volcanic rocks often associated with tridymite. Easily formed artificially.

DIAG.—The form, index, optic sign, and the reversible change of state at 200° to 275°C. are characteristic. Multiple twinning in bands of one or two intersecting sets is common. Elongated units may show extinction at any angle.

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[12] Wernicke: *Ann. Phys.*, CXXXIX, 1870, p. 146.

[13] *Inaug. Diss. Jena*, 1905; *Zeit. Kryst.*, XLIV, p. 313.

[14] H. Buttgenbach: *Minéraux et Roches*, 1916, p. 508.

Melanophlogite (SiO_2 with little SO_3 or SiS_2) is probably closely related to cristobalite. Crystals cubic. H. = 6.5–7. G. = 2.04. Insoluble. N = 1.461 (–1.45). Colorless or yellow; turns black on heating. Found with sulphur in Sicily. Very rare.

QUARTZ HEXAGONAL $c = 1.09997$ SiO_2

PHYS. CHAR.—Crystals usually prismatic, terminated by two rhombohedrons, $10\bar{1}1$ and $0\bar{1}11$. Sometimes in double six-sided pyramids made up of two rhombohedrons. Crystals also highly modified, and distorted. Horizontal striations common on prismatic faces. Massive forms common from coarse to fine granular or even to cryptocrystalline. Crystals often twinned by interpenetration; the twinning axis may be the vertical axis, and in this case the twins may be united so as to be symmetrical with respect to 0001 or $10\bar{1}0$ or $11\bar{2}0$. Much more rarely other twinning laws occur, thus, the twinning plane may be $11\bar{2}2$. Cleavage nearly always absent or very difficult; cleavage may be obtained by sudden cooling, which suggests that this cleavage pertains to the high temperature form only. Cleavage difficult parallel to $10\bar{1}1$ and $01\bar{1}1$, in traces parallel to $10\bar{1}0$ and 0001. H. = 7. G. = 2.653–2.654. Infusible. Insoluble in acids except in HF; difficultly attacked by alkalies.

OPT. PROP.—Uniaxial positive. Refringence low; birefringence weak. Rotary polarization (invisible in thin sections) increasing with the thickness of the section. Right-handed and left-handed crystals equally common; the combination of these two produces the Airy spirals.

The indices of refraction of quartz vary only in the fifth or sixth decimal place; averaging the most reliable measures the values are:

	Line C (Li)	Aver. of	Line D (Na)	Aver. of	Line E	Aver. of
N_e =	1.55087	8	1.55337	14	1.55637	6
N_o =	1.54192	6	1.54424	13	1.54718	6
$N_e - N_o$ =	0.00895		0.00913		0.00919	

Since the index for the ordinary ray does not vary with the orientation, the index $N_o = 1.5442$ (in white light the index is nearly the same as in sodium light) is constant in all sections and is useful for exact comparisons.

The refringence decreases very slowly with increase of temperature. The birefringence likewise decreases slowly with increase of temperature, but only to 570° C.; above that temperature there is an abrupt change, and the birefringence thereafter increases.

Quartz occurs sometimes showing a distinctly biaxial character. In this case 2E = 12°–18°, or, rarely, as much as 24°.

Quartz is colorless in thin sections, but often shows inclusions of various kinds which serve as pigments and give a color to thick sections and masses of the mineral. Thus quartz may be yellow, red, brown, green, blue, black.

INCL.—Liquid inclusions are especially characteristic of quartz. The liquid may be water, or CO_2, or both. Gaseous bubbles, sometimes movable, often accompany the liquid inclusions. These inclusions rarely occupy cavities which have the form of the enclosing mineral; such cavities are called negative crystals. Cubes, probably of NaCl, are sometimes found in these cavities. In other cases the liquid present is a carbide and causes the fetid odor of certain samples of quartz when struck a sharp blow.

The inclusions in quartz are usually arranged along lines, curved surfaces, or, sometimes, parallel to the crystal faces. They are occasionally very large, and visible to the naked eye. Other inclusions in quartz include reticulated rutile (*Venus' hair*), needles of tourmaline, of epidote, or actinolite or tremolite (when regularly arranged so as to produce opalescence these make the variety of quartz called *cat's eye*), of chlorite or of other slaty minerals. Quartz containing reticulated or acicular rutile, or other mineral, is often called *sagenite*.

INVER.—Upon heating, quartz undergoes a reversible inversion to a high temperature form which is also hexagonal, but has hexagonal trapezohedral symmetry while ordinary quartz has trigonal trapezohedral symmetry. The inversion temperature is sharp at 572° ± 5° C., and the change involves a 2 per cent change of volume. The high temperature form probably has rhombohedral cleavages. Quartz which was formed at temperatures above 575° and has inverted on cooling can be distinguished from quartz which has never been at that temperature by the following features:[15] (1) Crystal form, the presence of the trigonal trapezohedron or other evidence of tetartohedrism, which is evidence of the low temperature form. Simple rhombohedral, rather than prismatic rhombohedral, habit is an indication of the high temperature form. (2) Character of the twinning, especially as shown by etch figures on the basal pinacoid; in the low temperature form the twinning is simple and regular; in quartz which has inverted it is irregular in small patches bearing no relation to the external form. (3) Intergrowths of right- and left-handed quartz are more frequent and more regular in the low temperature form. (4) Inversion produces a shattering due to a distinct change of volume.

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[15] As given by F. E. Wright: *Am. Jour. Sci.*, XXVII, 1909, p. 438.

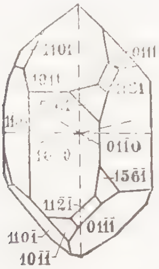

Fig. 35.—A crystal habit of low temperature quartz.

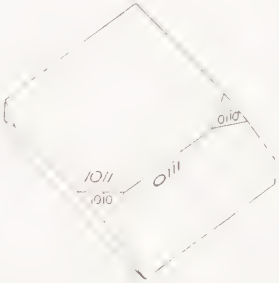

Fig. 36.—A crystal habit of high temperature quartz.

Quartz undergoes a second inversion at 870° C. to tridymite, and a third at 1470° C. to cristobalite, but these are very sluggish, and occur only under especially favorable conditions. These are also reversible.

Alter.—Quartz is a very stable mineral; in rare cases it is replaced by talc, pyrite, cassiterite, magnetite, etc. Inversely, quartz is found in pseudomorphs after many minerals, notably calcite, fluorite, barite, etc. When fused in nature "embayments" may first be formed, then the whole mass may be fused. In acid rocks fused quartz recrystallizes at high temperatures as tridymite (or cristobalite).

Occur.—Quartz is one of the most abundant minerals found in nature; it is an essential constituent of rhyolite, granite, dacite, tonalite, gneiss, micaschist, and many related rocks. It is usually the chief, and often, nearly the only, constituent of sandstone, gravel, conglomerate, and vein rocks. It occurs in less important amounts in many other igneous, metamorphic and sedimentary rocks. It is often deposited by hot springs and geysers.

In graphic granite skeleton crystals of quartz are arranged in parallel position in a very coarsely granitic aggregate of acid feldspar anhedra. In sandstone the grains are often enlarged by deposition of quartz oriented upon the enclosed grain.

Diag.—The low refringence, weak birefringence and absence of color, cleavage, or alteration usually serve to identify quartz. Distinguished from colorless fresh cordierite by the uniaxial character and lack of the twinning in the quartz. Other characters of importance include the specific gravity, hardness, crystal form, and resistance to acids, except HF.

Lechatelierite (SiO_2) is naturally fused amorphous silica. It is isotropic with G. = 2.19 and N = 1.458. Artificially fused quartz has the same index, N = 1.4588. But ignited silica hydrogel (or chemically precipitated silica) has N = 1.48–1.485. Lechatelierite is sometimes produced by lightning striking quartz sand and fusing tiny tubes (*fulgurites*) in it. It is also known about volcanoes. Rare.

Chalcedonite (SiO_2) is commonly called *chalcedony*; it is a fibrous form of crystalline silica, supposed to be specifically distinct from quartz, since it does not invert at 575° C.[16] But X-rays reveal the same crystal structure as in quartz, though the index is lower and the density is less.[17] H. = 6. G. = 2.55–2.63. F. = 7. Insoluble. $N_o = 1.537$ (1.533–1.539), $N_e = 1.530$, $N_o - N_e = 0.007$, but these figures are subject to correction, as the optic sign is uncertain, and the mineral may even be biaxial, as the fibers in some cases seem to have ± elongation, parallel to Γ; in other cases the elongation is said to be negative; in still other cases it is positive (*quartzine*). In some cases (*lutécite*), the extinction is at 29°, instead of being parallel. Many varieties of chalcedonite are recognized, depending upon color, structure, etc., such as *carnelian*, *sardonyx*, *jasper*, *chrysoprase*, *agate*, *onyx*, etc.

Opal ($SiO_2 \cdot nH_2O$) is amorphous silica with some water, perhaps merely adsorbed. It may be capable of absorbing much water and thus becoming more transparent. H. = 6 ±. G. = 2.1 ±. F. = 7. Soluble in HF and KOH. Isotropic, but may show polarization due to internal strain; globules then show a black cross of negative character like colloidal substances, *e.g.*, gelatin, which contract on solidifying. Refringence varies with the tenor of water.

With very little water	Common condition	With much water
N = 1.406	N = 1.44 – 1.45	1.46

Colorless, white, milky, yellow, brown, red, green, blue, black. Precious opal shows a play of colors. Colorless in thin section.

Inclusions of various pigments, etc., are common. By loss of water opal changes to chalcedony or other crystal form of silica. It is found in rocks of all kinds, but it is always of secondary origin. It may be formed by the alteration of silicates in igneous or metamorphic rocks; it may be deposited from solution about geysers or in veins, or cavities; it may be of organic origin; or it may be of concretionary origin in sedimentary rocks. The distinctive characters of opal are the monorefringent character, the distinct negative refringence, the mode of formation, the colloidal structure, the low specific gravity, and the solubility in alkalies as well as in HF.

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[16] Fenner: *Jour. Wash. Acad. Sci.*, II, 1912, p. 471.

[17] Washburn and Navias: *Proc. Nat. Acad. Sci.*, VIII, p. 1.

TRIDYMITE ORTHORHOMBIC (*Pseudohexagonal*) SiO_2

PHYS. CHAR.—Crystals usually six-sided basal plates; in random aggregates of minute units often showing wedge-like twinning. Basal plates show twinning on 110 in sectors as in aragonite and cordierite, the optic plane being normal to the external boundary. Occasional pseudoisometric forms are probably due to inversion from cristobalite. Indistinct prismatic cleavage and basal parting. H. = 7. G. = 2.27. F. = 7. Soluble in boiling Na_2CO_3.

OPT. PROP.—The optic plane is 100; the positive acute bisectrix is normal to 001. The refringence is negative and the birefringence weak.

$$(+)\ 2E = 60^\circ \pm \qquad 2V = 35^\circ \pm$$

$$N_g = 1.473\ \text{Na} \quad N_m = 1.469 + \quad N_p = 1.469 \quad N_g - N_p = 0.004$$

Colorless or white. Colorless in section.

INCL.—Gas inclusions are not infrequent.

INVER.—Tridymite is the stable form of silica between 870° and 1470° C.; it inverts to quartz below 870° and to cristobalite above 1470°, but these inversions are very sluggish, and tridymite may exist for long periods as a metastable form. This has permitted the determination of the fusing point of tridymite (1670° ± 10° C.), and the study of the mineral at ordinary temperatures. Tridymite inverts, on heating, to a form called β_1-tridymite at 117° C. and to another form called β_2-tridymite at 163° C. The former is hexagonal, and the substance is uniaxial above 117° C. The latter is uniaxial and hexagonal, the change at 163° C. being perhaps from hemihedral to holohedral symmetry. On cooling, the reversions show some lag.

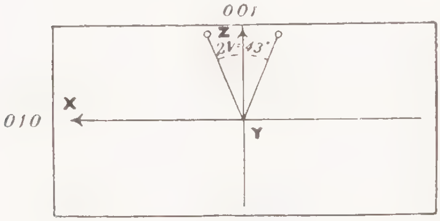


FIG. 37.—Optic orientation of tridymite.

OCCUR.—Aggregates of basal plates occur in lithophysæ; also known in meteorites.

DIAG.—Differs from cristobalite in its slightly higher index of refraction, its lath-shaped forms with negative elongation and parallel extinction and its wedge-shaped twins. Also, the inversion temperatures are characteristic.

BROOKITE ORTHORHOMBIC $a : b : c = 0.8416 : 1 : 0.4772$ TiO_2

PHYS. CHAR.—Known only in crystals which are of variable habit. Cleavages in traces parallel to 110 and 001. H. = 5.5-6. G. = 3.87-4.08. Infusible. Insoluble even in HF.

OPT. PROP.—The acute positive bisectrix (Z) is always perpendicular to 100, but in many crystals the plane of the optic axes is parallel to 001 for red and yellow light with $\rho > v$ and parallel to 010 for blue and green light with $\rho < v$; the mineral is uniaxial for a certain yellowish green tint. In some crystals the plane of the optic axes is parallel to 001 for light of all colors. The axial angle decreases with decreasing temperature, so that it is uniaxial for yellow light at − 190° C., with 2E = 26° (red).

$(+)\ 2E =$	55° 2′ Li	30° 16′ Na	0° (555 μμ) 33° 48′ Tl
$N_g =$	2.644-2.664 Li	2.705-2.741 Na	2.827 Tl
$N_m =$	2.542-2.651	2.585-2.588	2.688
$N_p =$	2.541-2.549	2.583-2.584	2.681
$N_g - N_p =$	0.103-0.115	0 121-0.158	0.146

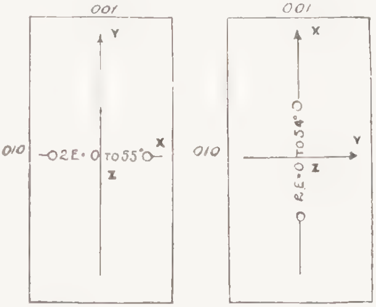
Color brown, yellowish, reddish, black. In thin section pleochroism weak in yellow and brown tints; absorption formula either $Z > Y > X$ or $Y > Z > X$.

Inver.—Changes to rutile at high temperature. Octahedrite forms at temperatures lower than those at which brookite forms artificially.

Occur.—In cavities of igneous and metamorphic rocks, and as a secondary product in various rocks. Rare.

Diag.—The form, the enormous dispersion, the extremely high relief and the strong birefringence are characteristic of brookite.

Tellurite (TeO_2) is orthorhombic with $a : b : c = 0.456 : 1 : 0.469$. Crystals 010 plates, often elongated parallel to c; perfect 010 cleavage. Flexible. H. = 2. G. = 5.9. Fusible. Soluble in NH_4OH. Optic plane is 100; $X = b$. Optic sign uncertain since the optic angle is very nearly equal to 90°. (+?) $2V = 90° \pm$, $\rho < v$, moderate. $N_g = 2.35$ Li, $N_m = 2.18$, $N_p = 2.00$, $N_g - N_p = 0.35$. Colorless, white, yellow; colorless in section. Artificial crystals are tetragonal with $c = 0.554$; these formed from solutions at low temperatures. Found with native tellurium in Colorado, Transylvania, etc. Very rare.



Figs. 38, 39.—Optic orientation of brookite for red and blue light, respectively.

Baddeleyite (ZrO_2) is monoclinic; $a : b : c = 0.987 : 1 : 0.511$, $\beta = 81° 14'$. Crystals usually twinned on 100 or 110, sometimes in thin lamellæ. Habit tabular parallel to 100. Perfect basal cleavage. H. = 6.5. G. = 5.7 ±. F. = 6. Decomposed by H_2SO_4. Optic plane is 010; $X \wedge c = +12°$. (−) $2E = 70°$, $2V = 30° \pm 1°$, $\rho > v$, rather strong. $N_g = 2.20$, $N_m = 2.19$, $N_p = 2.13$, $N_g - N_p = 0.07$. Colorless to black. Pleochroic, greenish yellow to brown with $X > Y > Z$. Tetragonal (and monoclinic?) forms of zirconia are known artificially; similar forms are reported in nature, but their properties and relations are almost wholly unknown. Found in gem sands in Ceylon and Brazil from rare rocks.

7. OXIDES OF HEXAVALENT ELEMENTS

Tungstite ($WO_3 \cdot H_2O$) is orthorhombic (?); composed of microscopic scales with one perfect cleavage assumed to be basal. H. = 2.5. G. = 5.5(?). F. = 7. Soluble in KOH, but not in acids. Acute bisectrix X normal to cleavage; (−) $2V$ = small, $\rho < v$ distinct. $N_g = 2.26$, $N_m = 2.24$, $N_p = 2.09$, $N_g - N_p = 0.17$. Color golden yellow to green. Luster earthy. Yellow in section. Some crystals show absorption with $X > Y > Z$. Associated with wolframite and gold in ore deposits. Rare.

Schoepite[18] ($UO_3 \cdot 2H_2O$) is orthorhombic with $a : b : c = 0.426 : 1 : 0.875$. Crystals prismatic, complex, with perfect 001 cleavage. G. = 5.69. $X = c$; (−) $2V$ = large, $\rho > v$. $N_g = 1.735$, $N_m = 1.714$, $N_p = 1.690$, $N_g - N_p = 0.045$. Color sulphur yellow with X = colorless and Y and Z = lemon yellow. Found in uranium ores from the Belgian Congo. Very rare.

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[18] T. L. Walker: *Am. Mineral.*, VIII, 1923, p. 67. S. G. Gordon (personal communication, 17 Dec., 1924) says that schoepite is crystallographically identical with becquerelite.

Becquerelite [19] ($UO_3 \cdot 2H_2O$) is also orthorhombic with $a : b : c = 0.554 : 1 : 0.594$. Crystals short domatic parallel to b with perfect 001 and distinct "101" (= 110?) cleavages. Twinning on 110. Optic plane is 100; $X = c$. (−) 2V = small, $\rho > v$. The optic angle decreases with heat and the mineral is uniaxial above 100° C. $N_g = 1.77$, $N_p = 1.75$, $N_g - N_p = 0.02$. Color dark amber yellow with X = ?, Y = yellow, Z = dark yellow. Found in uranium ores from the Belgian Congo. Very rare.

Soddite [20] ($12UO_3 \cdot 5SiO_2 \cdot 14H_2O$?) is orthorhombic. Crystals pyramidal or prismatic with a very small $110 : 1\bar{1}0$ angle. G. = 4.63. F. = easy in closed tube after turning black. Gelatinizes with HCl. Optic plane is 010; $Z = c$. Biaxial. (+) 2V = ?, N_g = ?, $N_m = 1.662$, $N_p = 1.645$. Color yellow. Found in uranium ores from the Belgian Congo. Very rare.

Fourmarierite [21] ($UO_3 \cdot H_2O$?) is orthorhombic with $a : b : c = 0.883 : 1 : 0.811$. Crystals are 100 tablets with H. = 3–4. G. = 6.05. Distinct 100 cleavage. Optic plane is 001 with $X = a$. (−) 2E = large. N_g, N_m and $N_p > 1.75$, $N_g - N_m = 0.018$. Color red with X = pale red-brown, Y = ?, Z = dark red-brown. Found in uranium ores from the Belgian Congo. Very rare.

8. OXIDES OF TRIVALENT AND DIVALENT ELEMENTS

SPINEL GROUP

The minerals of the spinel group (and also chrysoberyl, etc.) may be considered aluminates, ferrates, chromates, etc., of magnesium, iron, zinc or manganese; but the corresponding acids are hypothetical and X-ray work suggests that these minerals are double oxides. They are isometric, commonly in rounded grains with no distinct cleavage. Twinning on 111 ("spinel law") is not rare, as illustrated in spinel. Many of the pure end compounds are mutually miscible in all proportions, and many names have been given to intermediate types, which, in most cases, are not sharply defined. The chief types are the following:

Magnesioferrite	$MgFe_2O_4$	Picrochromite [22]	$MgCr_2O_4$
Chlorospinel	$Mg(Al,Fe)_2O_4$	Magnesiochromite	$Mg(Al,Cr)_2O_4$
Spinel	$MgAl_2O_4$	Gahnite	$ZnAl_2O_4$
Ceylonite	$(Mg,Fe)Al_2O_4$	Dysluite	$Zn(Al,Fe)_2O_4$
Picotite	$(Fe,Mg)(Al,Cr)_2O_4$	.... [23]	$ZnFe_2O_4$

[19] A. Schoep: *Comp. Rend.*, CLXXIV, 1922, p. 1240; *Bull. Soc. Fr. Min.*, XLVI, 1923. p. 9; XLVII, 1924, p. 147. Buttgenbach (*Ann. Soc. Geol. Belg.* annex to vol. XLVII, 1924, p. C31) gives for becquerelite: $a : b : c = 0.572 : 1 : 0.617$; (−) 2E = 57° 38′; $N_g - N_m = 0.0134$.

[20] A. Schoep: *Comp. Rend.*, CLXXIV, 1922, p. 1066: *Bull. Soc. Belg. Geol.*, XXXIII, 1923, p. 83.

[21] H. Buttgenbach: *Ann. Soc. Geol. Belg.*, annex to vol. XLVII, 1924, p. C41; A. Schoep: *Bull. Soc. Fr. Min.*, XLVII, 1924, p. 157.

[22] E. S. Simpson: *Min. Mag.*, XIX, 1920, p. 100.

[23] Not yet found in nature.

Hercynite	$FeAl_2O_4$	Franklinite	$(Zn,Mn)Fe_2O_4$
Chromohercynite	$Fe(Al,Cr)_2O_4$	Jacobsite	$MnFe_2O_4$
Chromite	$FeCr_2O_4$	Manganmagnetite	$(Fe,Mn)Fe_2O_4$
Chrompicotite	$(Mg,Fe)Cr_2O_4$	Magnetite	$FeFe_2O_4$
		Plumboferrite	$(Fe,Pb)Fe_2O_4$

Magnesioferrite ($MgFe_2O_4$) is isometric; crystals octahedral with no cleavage. H. = 6–6.5. G. = 4.6. F. = 7. Soluble in HCl. Strongly magnetic. Opaque except in very thin section. N = 2.35 Li. Color and streak black; dark red in transmitted light. Found with hematite about volcanoes. Rare. If opaque, only distinguished from magnetite by chemical tests for magnesium.

SPINEL ISOMETRIC $MgAl_2O_4$

PHYS. CHAR.—Crystals octahedral with imperfect 111 cleavage. Twinning on 111, sometimes multiple. H. = 8. G. = 3.6. Fuses at 2135° C. Slowly soluble in H_2SO_4.

OPT. PROP.—Isotropic with high refringence, increasing with depth of color, that is, with tenor of iron.

Pure spinel	Ceylonite	Picotite
N = 1.723	1.75–1.79	2.05

Color red, blue, green, yellow, brown, black; rarely nearly white. In thin section lighter shades; not pleochroic. *Ceylonite* or *pleonaste* is usually green with G. = 3.84 ±. *Picotite,* which contains dominant iron and a little chromium, is dark yellowish brown to greenish brown with G. = 4.1 ±. *Chlorospinel* is grass-green with G. = 3.59. Pure spinel is red, blue, pale green or colorless.

ALTER.—Usually unaltered even in much decayed rocks. It has been found changed to muscovite, steatite, serpentine.

OCCUR.—*Spinel* is found chiefly in crystalline limestones and schists. *Ceylonite* has been found with magnetite in igneous rocks, but is common in contact zones and schists. *Picotite* occurs in basic igneous rocks and serpentine; also known in schists.

DIAG.—Distinguished from garnet by its octahedral form and by the absence of silica.

Manganspinel ($MnAl_2O_4$) is known only in slags. Crystals octahedral without cleavage. H. = 7.5. G. = 4.05. F. = 7. Insoluble. Brown. Index estimated at 1.8 ±.

Hercynite ($FeAl_2O_4$) is isometric; fine granular massive. H. = 7.5. G. = 3.9. F. = 7. Insoluble. Isotropic with high refringence. N = 1.80 ± (pure), 1.775 (with 13.7 MgO). *Chromohercynite* has G. = 4.41; the index must be about 1.9. Color black; streak green; green in section; not pleochroic. Found in contact rocks rich in alumina. Rare. Green color and high index are notable.

CHROMITE Isometric $FeCr_2O_4$

Phys. Char.—Crystals octahedral; usually massive granular. Cleavage unknown. H. = 5.5. G. = 4.5. F. = 6 (in reducing flame). Insoluble.

Opt. Prop.—Isotropic with N = 2.07–2.16. Color iron to brownish black. In very thin flakes brown to red. Not pleochroic. Gray in vertical reflected light.

Occur.—In basic igneous rocks and serpentine. Also in dolomite and schists. Also in some meteorites.

Diag.—Higher index, greater density and deeper color than picotite; much less magnetism than magnetite.

Picrochromite is very imperfectly known; it must have lower density and lower refringence than chromite.

Gahnite ($ZnAl_2O_4$) is isometric; crystals octahedral, etc., with fair 111 cleavage. Twinning on 111. H. = 7.5–8. G. = 4.4–4.6. F. = 7. Slowly soluble in H_2SO_4. Isotropic with N = 1.81 (62 per cent gahnite, 30 per cent hercynite). A blue gahnite with ZnO = 34.48, FeO = 4.86 and CoO = 1.48 has N = 1.790 (Shannon [24]). Color green to black; rarely brown; in section lighter shades. Found in schists and in veins; also in pegmatites. Rare. Differs from garnet by high index, octahedral form and absence of silica; from other green and brown spinels by high index (except for picotite), associated zinc minerals and composition.

Jacobsite ($MnFe_2O_4$) is isometric; crystals octahedral. H. = 6. G. = 4.75. F. = 7. Soluble in HCl. Opaque or nearly so. Color deep black; streak blackish brown. Index of refraction probably about 2.3. Found in limestone in Sweden, etc. Rare.

Franklinite $\{(Zn,Mn)Fe_2O_4\}$ is similar, with octahedral parting; slightly magnetic. H. = 6. G. = 5.1. F. = 7. Soluble in HCl. Opaque except in very thin section. N = 2.36 ± Li. Iron black in mass; reddish brown in transmitted light. Grayish white in vertical reflected light. Found in calcite with zinc and manganese minerals at Franklin Furnace, N. J. Rare. Distinguished from magnetite by associated minerals, dark reddish brown streak, less magnetism and chemical tests for Mn and Zn.

MAGNETITE Isometric $FeFe_2O_4$

Comp.—Magnetite varies in composition between rather wide limits; not only may the ferrous iron be replaced by more or less Mn (*manganmagnetite*), Pb (*plumboferrite*), Mg, or even Ni, but the ferric iron may be replaced by more or less Ti (*titanomagnetite*), Al, Mn, or Cr. Further, if *martite* is not always pseudomorphous, there is a continuous series from magnetite to oxidized magnetite which is isometric Fe_2O_3.

Phys. Char.—Crystals commonly octahedrons; also dodecahedrons; cubes rare. Also massive, laminated or granular. Twinning on 111, sometimes lamellar. Octahedral parting may be well developed. Strongly magnetic; some crystals have polarity. H. = 6. G. = 5.17. F. = 6. Soluble in HCl.

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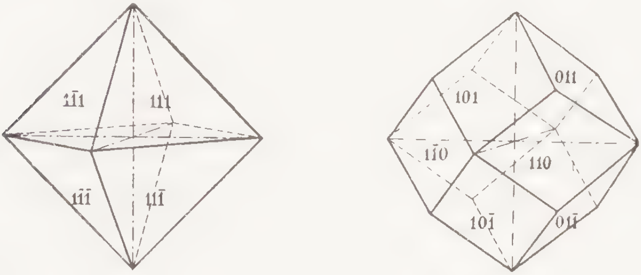
[24] *Am. Mineral.*, VIII, 1923, p. 147.

Opt. Prop.—Opaque in all artificial sections. Isotropic. N = 2.42 Na.[25] Color iron black; streak black. In extremely thin flakes between cleavage lamellæ of mica it is translucent and pale brown to black. Steel blue color in oblique reflected light. Grayish white in vertical reflected light. *Plumboferrite* has a black color with a red streak; it is only slightly magnetic; rare.



Figs. 40*a*, 40*b*.—Crystal forms of magnetite.

Alter.—Changes to hematite, limonite, or siderite.

Incl.—Apatite and zircon occur as inclusions in magnetite in some igneous rocks. By dissolving the enclosing magnetite, ilmenite has been found within so oriented that the trigonal axes of the two minerals are parallel. In other cases rutile needles have been found lying parallel with the octahedral edges.

Inver.—An inversion with a great decrease in magnetism is reported to occur at about 530° C.; this is probably an inversion of oxidized magnetite to hematite.

Occur.—Magnetite is very widespread in its occurrence in igneous and metamorphic rocks. It is found sparingly in acid rocks, but quite abundantly in some basic types, even forming masses of commercial importance associated with basic igneous rocks. Similar masses are sometimes formed by metamorphism of deposits of limonite and hematite. It is one of the earliest minerals to solidify from magmas, associated in time with apatite and zircon, and commonly enclosed in the ferromagnesian silicates. Recrystallization of augite at high temperature results in paramorphs of hornblende and biotite with borders of magnetite; cleavage lines of the transformed pyroxene may be marked also by magnetite.

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[25] S. Loria: *Proc. K. Akad. Wet. Amst.*, XIV, 1912, p. 972.

Diag.—Magnetite is distinguished from hematite and chromite by its blue-black color in reflected light. It is distinguished from graphite by its crystal form, hardness, and usually better metallic luster. It is distinguished from ilmenite by its crystal form, strong magnetism, and ready solubility in HCl. Ilmenite alters to leucoxene, but this may also develop from titaniferous magnetite.

Hausmannite ($MnMn_2O_4$) is tetragonal with $c = 1.166$; crystals pyramidal with distinct basal cleavage. Twinning on 101. H. = 5. G. = 4.8. F. = 7. Soluble in HCl. Uniaxial negative with $N_o = 2.46$ Li, $N_e = 2.15$, $N_o - N_e = 0.31$. Color brownish black; streak chestnut brown. In very thin section dark reddish brown; not pleochroic. Grayish white in vertical reflected light. In manganese ore deposits, as in Lake Superior region. Rare.

Heterolite ($ZnMn_2O_4$) is tetragonal; fibrous with perfect 001 cleavage. H. = 6. G. = 4.85. F. = 7. Soluble in HCl. Uniaxial negative with $N_o = 2.34 \pm$, $N_e = 2.14$, $N_o - N_e = 0.20 \pm$. A sample from Leadville with G. = 4.55 has $N_o = 2.26$, $N_e = 2.10$, $N_o - N_e = 0.16$ (Larsen). Color black; red-brown in section with $X > Z$, faint. Found in ore deposits. Very rare.

Högbomite[26] $\{Mg(Al,Fe)_4O_7?\}$ is trigonal with $c = 1.55$. Crystals rhombohedral without cleavage. H. = 6.5. G. = 3.81. F. = 7. Insoluble. Uniaxial negative with $N_o = 1.853$, $N_e = 1.803$, $N_o - N_e = 0.050$. A similar mineral[27] from Virginia has $N_o = 1.848$, $N_e = 1.817$, $N_o - N_e = 0.031$. Color black with X = light yellow-brown, Z = dark brown. Considered to be primary and also in part an alteration product of pleonaste. Rare.

CHRYSOBERYL Orth. $a : b : c = 0.471 : 1 : 0.582$ $BeAl_2O_4$

Phys. Char.—Crystals often tabular parallel to 100; 011 and 010 cleavages imperfect. Twinning on 031 cyclic, giving pseudohexagonal forms. H. = 8.5. G. = 3.64. F. = 7. Insoluble.

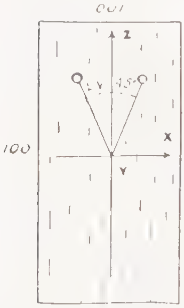

Fig. 41.—Optic orientation of chrysoberyl.

Opt. Prop.—Optic plane is 010; $Z = c$. Heat causes the optic axes to come together and then separate in the 001 plane. Optic angle very variable even in a single crystal.

$$(+)\ 2E = 85^\circ\ (12^\circ\text{–}125^\circ),\ 2V = 45^\circ, 67^\circ, 71^\circ,\ \rho < v.$$

$$N_g = 1.753\text{–}1.758\ \text{Na},\ N_m = 1.747\text{–}1.749,\ N_p = 1.744\text{–}1.747,$$
$$N_g - N_p = 0.009 \pm.$$

$$N'_g - N_p \text{ on the 011 cleavage} = 0.0035.$$

Color green of various shades, yellow, brown, red. Colorless in thin section. Pleochroic in thick sections with X = columbine red, Y = orange yellow, Z = emerald green. *Alexandrite* is a gem variety which is emerald green to gray, but columbine red by artificial light.

Occur.—In mica slate in the Urals; in pegmatite in New England, in alluvial deposits in Brazil and Ceylon.

Diag.—Very high relief with weak birefringence; very hard and high in density; infusible and insoluble.

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[26] A. Gavelin: *Bull. Geol. Inst. Upsala*, XV, 1916, p. 289.

[27] C. S. Ross in T. L. Watson: *Amer. Mineral.*, X, 1925, p. 1.

9. OTHER DOUBLE OXIDES

Zirkelite $\{(Ca,Fe)\,(Zr,Ti,Th)_2O_5\}$ is isometric and octahedral, often twinned on 111. No cleavage. H. = 5.5. G. = 4.72. F. = 7. Insoluble. Isotropic with N = 2.19. Color black; clear reddish brown in section. Found with baddeleyite. Very rare.

Naegite is probably related to malacon but contains ThO_2, Cb_2O_5, Y_2O_3 and UO_3 with much ZrO_2 and SiO_2. Probably tetragonal. H. = 7.5. G. = 4.09. Often nearly isotropic (due to alteration?) with N = 1.818. Color green or brown. Found in placers in Japan. Very rare.

MINIUMITE (*Minium*) TETRAGONAL(?) Pb_2PbO_4

PHYS. CHAR.—Fine powder; H. = 2-3. G. = 4.6. F. = 1.5.

OPT. PROP.—Refringence very high; negative elongation; parallel extinction; abnormal green interference color. N = 2.40 Li, $N_g - N_p$ = weak. Color vivid red; streak orange-yellow. Strongly pleochroic with X = deep reddish brown, Z = nearly colorless. Optic sign unknown.

OCCUR.—In ore deposits with galena.

BRAUNITE TETRAGONAL $c = 0.992$ $MnMnO_3$

COMP.—Always contains some $MnSiO_3$ (in crystal solution?).

PHYS. CHAR.—Crystals pyramidal with perfect 111 cleavage. H. = 6–6.5. G. = 4.8. F. = 7. Soluble in HCl.

OPT. PROP.—Opaque. Color and streak dark brownish black to steel gray. Luster submetallic. Grayish white in vertical reflected light.

OCCUR.—In manganese deposits. Rare.

Chalcophanite $\{(Mn,Zn)O\cdot 2MnO_2\cdot 2H_2O\}$ is trigonal with $c = 3.527$. Crystals rhombohedral with perfect basal cleavage. H. = 2.5. G. = 3.91. F. = 6. Soluble in HCl. Uniaxial negative with $N_o > 2.72$ Li, N_e = near 2.72, $N_o - N_e$ = extremely high. Color black with striking pleochroism; X = deep red, Z = nearly opaque. Found in ore deposits. Rare.

Langbanite ($mMnMnO_3\cdot nFe_2O_3\cdot pSb_2O_3$ with SiO_2?) is perhaps a silicate; it is trigonal with $c = 1.441$. Crystals complex and varied without cleavage. H. = 6.5. G. = 4.6-4.8. F. = 7. Slowly soluble in HCl. Uniaxial negative with $N_o = 2.36$, $N_e = 2.31$, $N_o - N_e = 0.05$ Li. Color black; slightly pleochroic in section in dark reddish brown with $X < Z$. Found in ore deposits in Sweden. Very rare.

ILMENITE GROUP

The ilmenite group includes several trigonal oxides of titanium and iron, manganese, or magnesium. Chemically, but not crystallographically, they are closely related to perovskite ($CaTiO_3$), which is regarded as a titanate of calcium, while crystallographically they are related to hematite as shown by the fact that ilmenite ($FeTiO_3$) may take up to 30 per cent of hematite ($FeFeO_3$) into crystal solution; at about 50 per cent the mixture produces a perthitic intergrowth known as *washingtonite*.[28] The minerals of the ilmenite group are the following:

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[28] A. Lacroix: *Minéral. Madagascar*, I, 1922, p. 266.

Ilmenite	$c = 1.37\text{-}1.38$[29]	G. = 4.8-4.9	$FeTiO_3 \cdot nFeFeO_3$
Crichtonite	$c = 1.385$	G. = 4.6	$FeTiO_3$
Picroilmenite	$c = ?$	. . . .	$(Fe,Mg)TiO_3$
Geikielite	$c = 1.370$	G. = 4	$MgTiO_3$
Pyrophanite	$c = 1.369$	G. = 4.5	$MnTiO_3$
Senaite	$c = 1.329$	G. = 5.3	$(Fe,Pb)(Ti,Mn)O_3$?

ILMENITE (*Menaccanite*) TRIG. $c = 1.37$ to 1.38 $FeTiO_3 \cdot nFeFeO_3$
CRICHTONITE TRIGONAL $c = 1.385$ $FeTiO_3$

COMP.—Fe_2O_3 present up to about 30 per cent.

PHYS. CHAR.—Crystals rhombohedral with base, etc.; lamellar. Twinning on 0001 or $10\bar{1}1$. Basal cleavage or parting. H. = 5.5. G. = 4.6–4.9. F. = 7. Slowly soluble in HCl.

OPT. PROP.—Opaque; rarely slightly translucent and dark brown with extremely high refringence and very strong birefringence. Luster metallic or submetallic. In reflected light crichtonite is violet black, ilmenite iron black, becoming brownish black with much Fe_2O_3.

ALTER.—Often alters to *leucoxene*, an opaque whitish aggregate supposed to be a variety of titanite; this may be accompanied by rutile. In phyllites ilmenite alters to siderite and rutile; rarely to octahedrite.

OCCUR.—A common but sparse constituent of igneous rocks; not rare in metamorphic rocks; found in veins and alluvial sands.

DIAG.—Ilmenite is only slightly magnetic. In thin section distinguishable from magnetite with much difficulty—the leucoxene alteration is evidence of titanium. A rapid and convenient microchemical test for titanium can be made by dissolving the mineral (a minute amount is sufficient) in HCl, and adding a drop of the solution to an H_2SO_4 solution of morphine producing a crimson color, or of phenol producing a brick red color, or of papaverine producing a violet color.

GEIKIELITE TRIGONAL $c = 1.370$ $MgTiO_3$
PICROILMENITE TRIGONAL $c = ?$ $(Fe,Mg)TiO_3$

PHYS. CHAR.—Massive, in pebbles, with perfect rhombohedral cleavages at about $93\frac{1}{2}°$. H. = 6. G. = 3.9 (geikielite) to 4.2 (picroilmenite). F. = 7. Slowly soluble in HCl.

OPT. PROP.—Translucent in thin section and uniaxial negative, with $N_o = 2.31$, $N_e = 1.95$, $N_o - N_e = 0.36$ for geikielite. Color in mass, black with metallic luster. In fine powder or thin section the color is a distinctive deep reddish purple. Streak purplish brown. Picroilmenite has darker color than geikielite.

ALTER.—Alters easily to leucoxene; also to rutile, titanite, limonite.

OCCUR.—In gem placers of Ceylon. Rare.

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[29] G. Doby and G. Melczer: *Zeit. Kryst.*, XXXIX, 1904, p. 526.

DIAG.—Uniaxial negative and purple with extreme birefringence; contains titanium—for tests see ilmenite.

Pyrophanite ($MnTiO_3$) is trigonal with $c = 1.369$; crystals very thin basal plates with perfect $02\bar{2}1$ and distinct $10\bar{1}2$ cleavages. H. = 5. G. = 4.54. F. = 7. Soluble in HCl. Uniaxial negative with $N_o = 2.441$ Li, 2.481 Na, $N_e = 2.210$ Na, $N_o - N_e = 0.271$. Color dark blood red; streak ocher yellow, slightly greenish; in thin section yellowish red, not pleochroic. Found in ore deposits in Sweden. Very rare.

Senaite $\{(Fe,Pb)\ (Ti,Mn)O_3?\}$ is trigonal with $c = 1.329$. Twinning on $11\bar{2}0$ common. No cleavage. H. = 6. G. = 4.8–5.3. Uniaxial negative with $N_o = 2.50$ Li, $N_o - N_e$ = low or moderate. Color black; nearly opaque and not pleochroic. Found in diamond sands of Brazil. Very rare.

Pseudobrookite ($Fe_4Ti_3O_{12}$?) is orthorhombic with $a : b : c = 0.878 : 1 : 0.885$. Crystals 100 tablets with distinct 001 cleavage. H. = 6. G. = 4.4–4.9. F. = 7. Decomposed by H_2SO_4. The optic plane is 010; $Z = a$. (+) $2V = 50° \pm$, $\rho < v$ distinct. $N_g = 2.42$ Li, $N_m = 2.39$, $N_p = 2.38$, $N_g - N_p = 0.04$. Again[30] N_g = near 2.375, N_m = ?, $N_p = 2.345–2.350$. Color dark brown to black; weakly pleochroic in reddish brown with $X < Y > Z$. Found in cavities in igneous rocks. Rare. Differs from brookite in form, solubility in H_2SO_4, larger optic angle, and absence of marked dispersion.

Cervantite ($Sb_2O_3 \cdot Sb_2O_5$?) is orthorhombic; crystals acicular or powdery. H. = 4–5. G. = 4. F. = 7. Soluble in HCl. Optic data on analyzed material lacking; data therefore unreliable. Samples labeled cervantite give varying results as follows: N = 1.88–2.06, isotropic or weakly birefringent (stibiconite?) also strongly birefringent. Color yellow to white; colorless in section. Oxidation product of stibnite, etc. Uncommon.

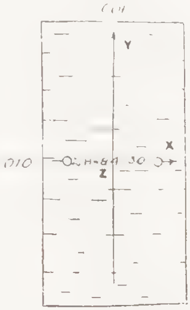

FIG. 42.—Optic orientation of pseudobrookite.

Stibioconite ($Sb_2O_3 \cdot Sb_2O_5 \cdot nH_2O$?) is variable in optic properties and doubtless also in composition, several minerals being included under one name. Most of the material is apparently amorphous with H. = 4–5. G. = 5.1–5.3. F. = 7. Insoluble. Isotropic with N = 1.6–1.87. Part of the material is birefringent with $N_m = 1.71–1.77$, $N_g - N_p = 0.01$, positive elongation and parallel extinction. Also N = 1.91–1.97, $N_g - N_p$ = moderate. Color white, gray, yellow. Found in ore deposits. Rare.

Arizonite ($Fe_2Ti_3O_9$) is monoclinic (?) with $a : b : c = 1.88 : 1 : 2.3$, $\beta = 55°$. H. = 5.5. G. = 4.25. Conchoidal fracture. Decomposed by hot H_2SO_4. Translucent only on very thin edges in blood red with $X < Z$. $N_m = 2.62$ Li, $N_g - N_p$ = moderate. Color steel gray. Found in pegmatite. Very rare.

Ulrichite (UO_2?) is crystallized isometric *pitchblende*;[31] *uraninite* ($UO_2 \cdot 2UO_3$?) is then the uncrystallized type of pitchblende; the composition is very variable and complex, usually including notable amounts of PbO, ThO_2, Y_2O_3, and minor amounts of many other substances. Crystals octahedral or cubic; usually massive. H. = 5.5. G. = 9. F. = 7. Soluble in HNO_3. Not magnetic. Opaque; color black with grayish, greenish, brownish or velvet tints. Streak brownish black, grayish, olive-green. Luster submetallic to greasy or pitch-like; also dull. Found in pegmatite and metalliferous veins. Rare.

Gummite is a very complex alteration product of uraninite resembling gum. H. =

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[30] *N. Jahrb. Min.*, I, 1926, p. 248.

[31] G. Kirsch: *Tsch. Min. Pet. Mit.*, XXXVIII, 1925, p. 227.

2.5. G. = 4 ±. F. = 7. Soluble in acid. Isotropic with N = 1.61 ±. Color yellow, red, etc. May be crystalline. Found only with uraninite.

Brannerite [32] (chiefly $TiO_2,UO_3,UO_2ThO_2,Y_2O_3,CaO$) is perhaps related to uraninite, though it may be a titanate. Crystals pseudotetragonal prismatic. H. = 4.5. G. = 4.5–5.4. Soluble in acid. Isotropic with N = 2.30 Na. Color black; splinters green to reddish brown. Found in placers in a region of pegmatites. Very rare.

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[32] F. L. Hess and R. C. Wells: *Jour. Franklin Inst.*, CLXXXIX, 1920, p. 225.

V. CARBONATES

This division includes all natural carbonates whose optic properties have been measured; it also includes natural compounds involving other carbon acids. Nitrates are added because some of them are crystallographically very similar to carbonates.

1. CARBONATES OF MONOVALENT BASES

Tronite or *trona* ($HNa_3C_2O_6 \cdot 2H_2O$) is monoclinic with $a : b : c = 2.843 : 1 : 2.949$, $\beta = 76° 31'$. Crystals 001 tablets or elongated parallel to *b*. Perfect 100 cleavage. H. = 3. G. = 2.13. F. = 1.5. Very soluble in water. Optic plane and X normal to 010; $Y \wedge c = + 7°$. $(-)\ 2V = 72°$, $\rho < v$, marked. $N_g = 1.540$, $N_m = 1.492$, $N_p = 1.412$, $N_g - N_p = 0.128$.[1] Colorless. Common in some arid regions as an efflorescence or lake deposit.

2. ANHYDROUS NORMAL CARBONATES OF DIVALENT BASES

CALCITE GROUP

The minerals of the calcite group are carbonates (of divalent metals) having trigonal symmetry. Crystals are commonly rhombohedral in aspect, but calcite exhibits a great variety of crystal habits. These minerals are often compact, fibrous, or granular; rarely lamellar or stalactitic. They all have perfect rhombohedral cleavage, and a hardness of 3 to 5; they are uniaxial and negative. The chief species and subspecies are the following:

Species	Subspecies	Axis *c*	Cleavage angle	Composition
Calcite	....	0.8543	74° 55′	$CaCO_3$
Dolomite	Magnesiodolomite	0.8322	73° 45′	$CaMgC_2O_6$
	Ankerite	0.811±	......	$Ca(Mg,Fe)C_2O_6$
	Ferrodolomite	....	......	$CaFeC_2O_6$
	Mangandolomite	....	......	$CaMnC_2O_6$
	Magnesite	0.8095	72° 30′	$MgCO_3$
	Mesitite	0.8141	72° 46′	$(Mg,Fe)CO_3$
	Siderite	0.8184	73° 0′	$FeCO_3$
	Rhodochrosite	0.8259	73° 9′	$MnCO_3$
	Smithsonite	0.8063	72° 20′	$ZnCO_3$
Spherocobaltite		....	......	$CoCO_3$

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[1] Data of Larsen given above. Buttgenbach (*Ann. Soc. Géol. Belg.*, XLII, 1919, p. 93) gives $Z \wedge 100 = 43°$ and $N_g - N_p$ between 0.035 and 0.055. Des Cloizeaux gives: $(-)\ 2V = 76°$, $\rho < v$, $N_m = 1.500$ red; Zepharovich gives: $N_m = 1.507$ D, $Y \wedge c = 6°$.

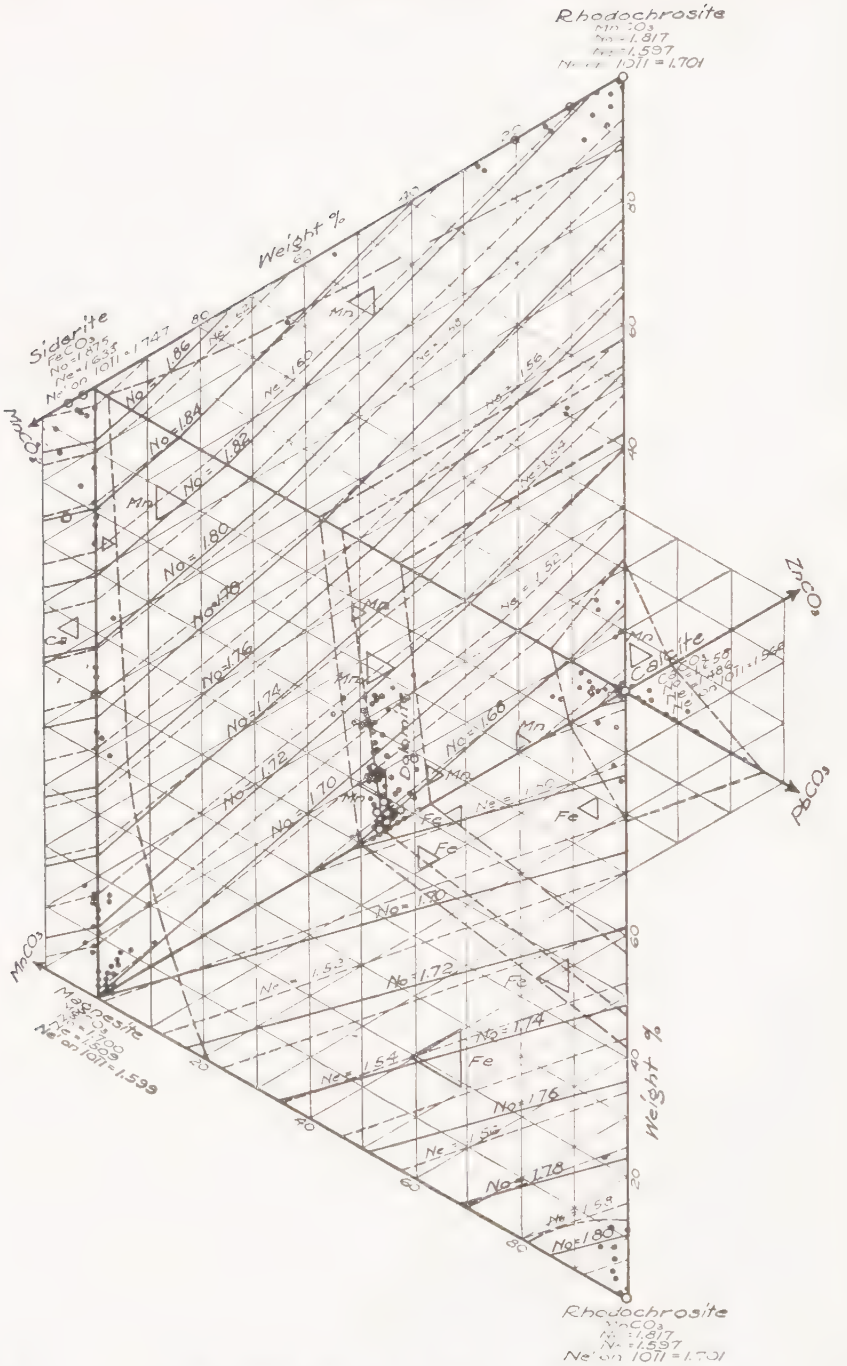


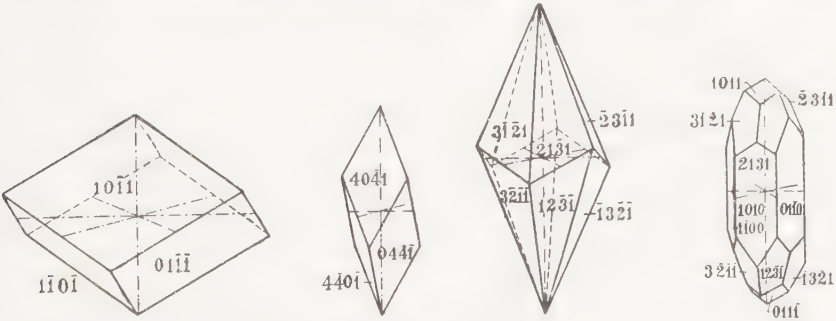
FIG. 43.—Variations of optic properties and estimated limits of mutual solubilities in that part of the calcite group which has $CaCO_3$ as one end member. Each dot represents an analysis and each small circle an analysis with optic data.

It is probable, but not yet certain, that smithsonite is miscible in all proportions with siderite and perhaps also with rhodochrosite. The magnesite-siderite-rhodochrosite (-smithsonite?) species has not yet been named. The solubility of spherocobaltite in siderite, etc., is unknown; it may be a subspecies like smithsonite.

The variations in optic properties and estimated limits of mutual solubilities are shown in Fig. 43 for that part of the calcite group which has $CaCO_3$ as one end-member.

CALCITE TRIGONAL $c = 0.8543$ $CaCO_3$

PHYS. CHAR.—Crystals of extreme diversity of habit sometimes highly complex; often rhombohedral in aspect; also scalenohedral. Twinning on 0001; also common lamellar twinning on $01\bar{1}2$, probably due in part to strains in grinding as such twins are easily produced artificially as described on page 17 of Part I. Other types of twinning less common. Perfect 1011 cleavage. H. = 3. G. = 2.715. F. = 7, but dissociates at 900° C. Under a pressure of 170 atmospheres of CO_2 calcite inverts at 970° C. and fuses at 1290° C. Easily soluble in cold dilute acid with effervescence.



FIGS. 44–47.—Crystal habits of calcite.

OPT. PROP.—Uniaxial negative with extreme birefringence.

	Li 671 μμ	Na 589 μμ	486 μμ
$N_o =$	1.6537	1.6584	1.6679
$N_e =$	1.4843	1.4864	1.4907
$N_o - N_e =$	0.1694	0.1720	0.1772

N'_e on the cleavage of calcite is 1.566.

Colorless, white, gray, red, green, blue, violet, yellow, brown, black. Colorless in thin section.

Manganocalcite[2] with about 20 (molecular) per cent of $MnCO_3$ has $N_o = 1.69$.

Plumbocalcite with 1.9 per cent $PbCO_3$ has[3] $N_o = 1.6668$, $N_e = 1.4904$, $N_o - N_e = 0.1764$.

INVER.—Calcite is the stable form of $CaCO_3$ up to 970° C. at which temperature it undergoes a reversible inversion[4] to α-$CaCO_3$, which is probably trirhombohedral like dolomite; it is stable only under pressure and fuses under 110 atmospheres of CO_2 at 1290° C. It is said[5] to have good $01\bar{1}2$ cleavage, and, after cooling, to be apparently biaxial with $2E = 15° \pm$ and incomplete extinction, these features characterizing calcite formed above 970° C., according to Walker and Parsons. Aragonite and another unstable form[6] (μ-$CaCO_3$) crystallize from solution at temperatures up to 90° C.; they change into calcite in a few days at 100° C., and more rapidly at higher temperatures. The very unstable μ-$CaCO_3$ forms hexagonal plates which have $G. = 2.54$ and are uniaxial positive with $N_o = 1.550$, $N_e = 1.650$, $N_e - N_o = 0.100$. "Vaterite" is a spherulitic variety[7] of μ-$CaCO_3$.

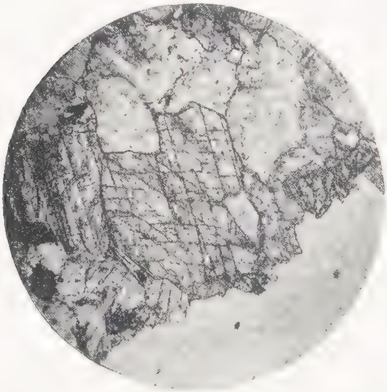


FIG. 48.—Photomicrograph of calcite showing three directions of cleavage.

ALTER.—Calcite is rather soluble in surface waters, but otherwise very stable.

OCCUR.—Not only the chief constituent of all kinds of limestone and marble, but also very common in veins and other ore deposits, as well as in igneous rocks, where it is nearly always an alteration product.

DIAG. Extremely strong birefringence, uniaxial negative character, relief commonly visibly varying from moderate to low on rotation, and rhombohedral cleavages with parallel lamellar twinning are diagnostic characters in thin section. Differs from other members of the calcite group, except dolomite and magnesite, in having one index lower than that of Canada balsam. Differs from dolomite and magnesite in its very ready solubility in cold dilute acid, low specific gravity, and common lamellar twinning. Dolomite often shows crystal boundaries. A method of distinction based on staining is described on page 39 of Part I.

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[2] N. Sundius: *Tsch. Min. Pet. Mit.*, XXXVIII, 1925, p. 175.

[3] P. Gaubert: *Bull. Soc. Fr. Min.*, XLII, 1919, p. 88.

[4] H. E. Boeke: *N. Jahrb. Min.*, 1912, I, p. 91.

[5] *U. Toronto Studies, Geol. Ser.*, XX, 1925, p. 14.

[6] *Am. Jour. Sci.*, CXCI, 1916, p. 473.

[7] Gibson, Wyckoff and Merwin: *Am. Jour. Sci.*, CCX, 1925, p. 325.

DOLOMITE TRIGONAL $c = 0.8322$ $CaCO_3 \cdot (Mg,Fe,Mn)CO_3$

COMP.—The common dolomite is nearly pure $CaMgC_2O_6$ or *magnesiodolomite*; this is miscible in all proportions with *ferrodolomite*, $CaFeC_2O_6$ and with *mangandolomite*, $CaMnC_2O_6$; limited amounts of $CaCaC_2O_6$ or $MgMgC_2O_6$ seem to enter dolomite crystals in some cases. Types intermediate between magnesiodolomite and ferrodolomite are known as *ankerite*.

PHYS. CHAR.—Crystals commonly rhombohedral in habit, rhombohedral faces often curved; crystal forms common even in massive rocks; twinning on 0001 or $10\bar{1}1$. Perfect 1011 cleavages. H. = 3.5–4. G. = 2.87. F. = 7. Only slowly soluble in cold dilute acid with effervescence.

OPT. PROP.—Uniaxial negative with extreme birefringence. The refringence and birefringence increase with increase of iron or manganese, as shown in Fig. 49.

Composition[8]		706.5 $\mu\mu$ (red)	589 $\mu\mu$ (Na)	404.7 $\mu\mu$ (violet)	
$MgCO_3$ = 50.7	N_o =	1.6733	1.6799	1.7030	
$CaCO_3$ = 49.2	N_e =	1.4984	1.5013	1.5110	G. = 2.882
$FeCO_3$ = 0.1	$N_o - N_e$ =	0.1749	0.1786	0.1920	

	Magnesiodolomite			Ankerite		Ferro-dolomite	Mangan-dolomite
$CaMgC_2O_6$	100.0[9]	90.0[10]	80.0[10]	46.8[9]	24.7[9]	0.0[9]	0.0[9]
$CaFeC_2O_6$	0.0	8.0	20.0	51.8	70.6	100.0	0.0
$CaMnC_2O_6$	0.0	0.0	0.0	0.0	4.6	0.0	100.0
N_o =	1.679	1.686	1.698	?	1.741	1.776	1.743
N_e =	1.502	1.505	1.513	?	1.536	1.565	1.546
$N_o - N_e$ =	0.177	0.181	0.187	?	0.205	0.211	0.197
G. =	2.87	2.94	?	2.99	3.12	3.36	3.34
N'_e on $10\bar{1}1$ =	1.588					1.67 ±	1.64 ±

Color white, reddish, greenish, pink, brown, gray, black. Colorless in thin section.

OCCUR.—Magnesiodolomite is the chief constituent of the rock known as dolomite and of dolomite-marble; it is common in some limestones and not rare as a secondary mineral in igneous and other rocks. X-ray analysis of the residue left after evaporation of centrifuged Lake Mendota water, which contains the constituents of magnesiodolomite in correct proportions, does not produce that mineral, but, instead, abundant aragonite, little calcite, and strictly amorphous material. Ferrodolomite, ankerite, and mangandolomite are found uncommonly in veins, etc.

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[8] P. Koller: *N. Jahrb. Min. Beil. Bd.*, XLII, 1918, p. 457.

[9] W. E. Ford: *Trans. Conn. Acad. Sci.*, XXII, 1917, p. 213.

[10] K. Eisenhuth: *Zeit. Kryst.*, XXXV, 1902, p. 607.

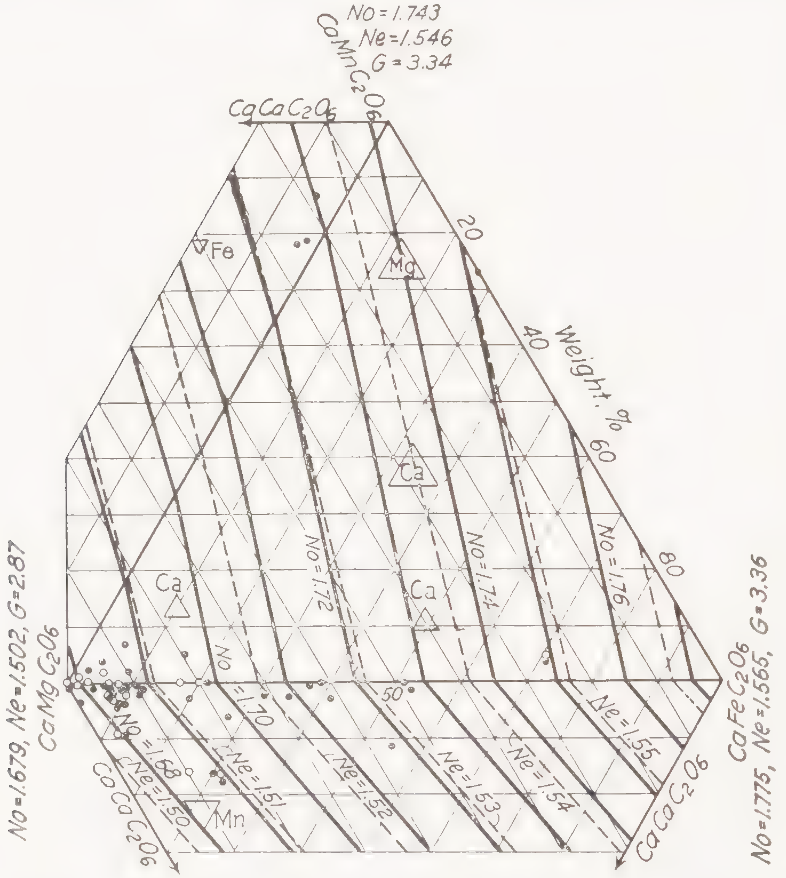

FIG. 49.—Variations of composition and optic properties in the dolomite system. Each dot represents an analysis and each small circle an analysis with optic data.

DIAG.—Distinguished from calcite by tendency to crystal outlines, usual absence of lamellar twinning, only slow solubility in cold dilute acids, and higher specific gravity.

MAGNESITE TRIGONAL $c = 0.8095$ $MgCO_3$

COMP.—Magnesium may be replaced by iron in any amount and magnesite thus grades into siderite. Crook [11] has defined the intermediate types as follows: *breunnerite* 95–70 per cent $MgCO_3$; *mesitite* 70–50 per cent $MgCO_3$; *pistomesite* 50–30 per cent $MgCO_3$, and *sideroplesite* 30–5 per cent $MgCO_3$, the remainder being $FeCO_3$ in each case.

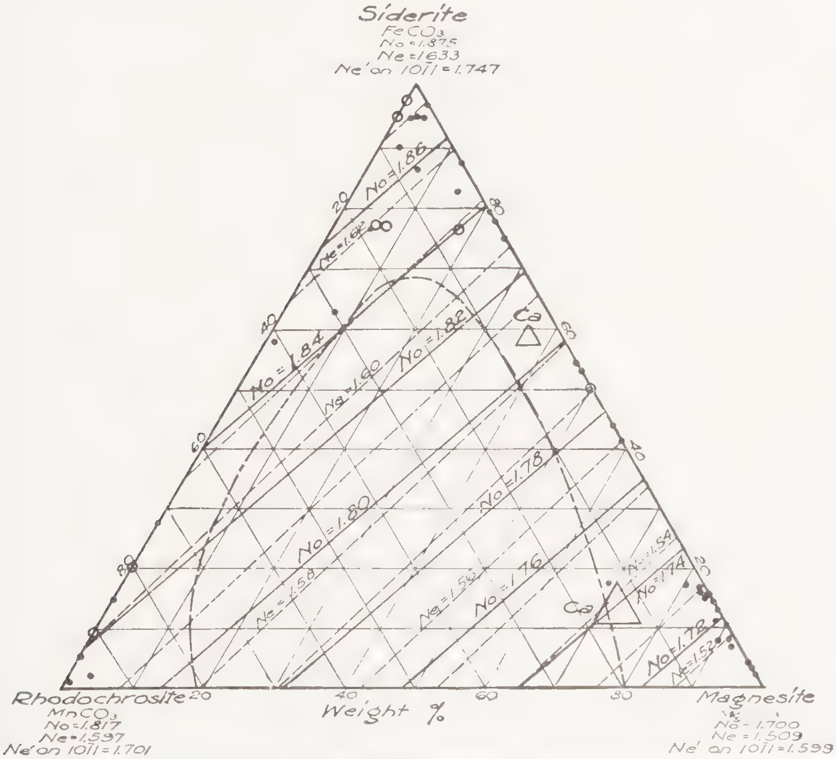

FIG. 50.—Variations of optic properties and estimated limits of mutual solubilities in the rhodochrosite-siderite-magnesite system. Each dot represents an analysis and each small circle an analysis with optic data.

PHYS. CHAR.—Crystals rare, rhombohedral or prismatic. Perfect $10\bar{1}1$ cleavage. Lamellar twinning not found. H. = 3.5–4. G. = 2.96. F. = 7. Insoluble in cold acid; readily soluble in hot acid with effervescence.

OPT. PROP.—Uniaxial negative with extreme birefringence. Refringence and birefringence increase as iron replaces magnesium, as follows, and as shown in Fig. 50:

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[11] T. Crook: *Trans. Ceram. Soc.*, XVIII, 1919, p. 67.

	Magnesite[9]	Breunnerite[9]	Mesitite[12]	Pistomesite[9]		Sideroplesite[9]	Siderite[9]
$MgCO_3$	100.0	91.	65.8	49.8	23.3	9.1	0.0
$FeCO_3$	0.0	9.	16.3	50.2	73.2	83.6	100.0
$N_o =$	1.700	1.707	1.719	1.788	1.830	1.847	1.875
$N_e =$	1.509	1.517	1.527	1.570	1.596	1.613	1.633
$N_o - N_e =$	0.191	0.190	0.192	0.218	0.234	0.234	0.242
$G. =$	2.96		3.12				3.89

N'_e on the cleavage[13] of magnesite is 1.599.

Magnesite is white, yellowish, grayish, brown, colorless in section.

Occur.—Found in some chlorite and talc schists, in serpentine, etc. Upon evaporation of an aqueous solution at 100° C. $MgCO_3$ is largely decomposed, leaving MgO;[13a] crystalline magnesite is produced by heating a closed tube containing $H_2MgC_2O_6$ to 150° C.

Diag.—Distinguished from calcite by absence of lamellar twinning and from calcite and dolomite by insolubility in cold dilute acid and somewhat higher specific gravity.

SIDERITE TRIGONAL $c = 0.8184$ $FeCO_3$

Comp.—Iron may be replaced by magnesium thus grading into magnesite, or by manganese, thus grading (through *oligonite*) into rhodochrosite, and probably in any proportion by zinc, and perhaps cobalt, thus grading into smithsonite and spherocobaltite.

Phys. Char.—Crystals commonly rhombohedral with perfect $10\bar{1}1$ cleavage. Crystal faces often curved. Twinning on $01\bar{1}2$, often with enclosed lamellæ. H. = 3.5–4. G. = 3.89. F. = 4.5, with decrepitation, becoming magnetic. Soluble in hot HCl with effervescence.

Opt. Prop.—Uniaxial negative with extreme birefringence. Refringence and birefringence decrease as iron is replaced (by magnesium—see magnesite or) by manganese, as follows:

	Siderite[9]	Siderite[14]	Oligonite[9]		Rhodochrosite[9]
$FeCO_3$	100.0	97.7	77.2	19.9	0.0
$MnCO_3$	0.0	1.8	15.8	79.3	100.0
$N_o =$	1.875	1.8724 Na	1.849	1.8279	1.817
$N_e =$	1.633	1.6338	1.615	1.6057	1.597
$N_o - N_e =$	0.242	0.2386	0.234	0.2222	0.220
N'_e on $10\bar{1}1 =$	1.747				1.701

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[12] P. Gaubert: *Bull. Soc. Fr. Min.*, XLII, 1919, p. 93, with 12.8 $MnCO_3$ and 1.2 $CaCO_3$(?).

[13] A. F. Rogers: *Am. Mineral.*, VIII, 1923, p. 138.

[13a] G. Kemmerer; personal communication, April 16, 1927.

[14] A. Hutchinson: *Mineral Mag.*, XIII, 1903, p. 209.

These variations are illustrated in Fig. 50.

Siderite[15] with about 6.0 per cent $(Ca,Mg)CO_3$ has: $N_o = 1.851$, $N_e = 1.612$, $N_o - N_e = 0.239$.

Siderite is gray, or, rarely, green; by alteration it becomes brown to red. In thin section it is ashen gray to colorless; absorption often distinct with $X < Z$.

ALTER.—Changes readily, on exposure, to limonite or hematite, or even to magnetite.

OCCUR.—Found in many sedimentary and metamorphic rocks, as limestone, clay iron stone, clay slate, mica slate, gneiss, etc. Also often associated with metallic ores in veins. Occasionally found as a secondary constituent of basic igneous rocks.

DIAG.—Differs from calcite, dolomite and magnesite in having *both* indices of refraction decidedly higher than that of Canada balsam; also in the common presence of limonite as an alteration product, and higher specific gravity. It differs from calcite and dolomite in its insolubility in cold dilute acid, and from dolomite and magnesite in the common presence of lamellar twinning. It also has an ashen gray color with distinct absorption, which is especially characteristic, although not pronounced.

RHODOCHROSITE TRIGONAL $c = 0.8259$ $MnCO_3$

COMP.—Manganese may be replaced by iron in any amount and the mineral thus grades into siderite. The limits (if any) of replacement by magnesium, zinc and cobalt are unknown.

PHYS. CHAR.—Crystals uncommon, usually rhombohedral. Perfect $10\bar{1}1$ cleavage. H. = 3.5–4.5. G = 3.70. F. = 7, but decrepitates and turns black. Soluble in warm acid with effervescence.

OPT. PROP.—Uniaxial negative with extreme birefringence. Refringence[16] and birefringence increase with increase of iron, as shown under siderite. See also Fig. 50.

$N_o = 1.818$ $N_e = 1.595$ $N_o - N_e = 0.223$

N'_e on the $10\bar{1}1$ cleavage = 1.701.

Color rose red, dark red, yellowish gray, brown. Colorless in section.

ALTER.—Changes to pyrolusite rather readily.

OCCUR.—Found especially in veins with ores of silver, lead and copper.

DIAG.—Differs from other members of the group in the usual pink color, the associated minerals, alteration to pyrolusite, and presence of manganese.

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[15] E. V. Shannon: *Proc. U. S. Nat. Mus.*, LXII, 1923, Art. 12.

[16] For data see *Trans. Conn. Acad. Sci.*, XXII, 1917, p. 211; *Bull. Soc. Fr. Min.*, XLII, 1919, p. 88; *Jour. Wash. Acad. Sci.*, VII, 1917, p. 365; N. Sundius: *Tsch. Min. Pet. Mit.*, XXXVIII, 1925, p. 175; *Min. Abst.*, III, 1926, p. 124.

SMITHSONITE TRIGONAL $c = 0.8063$ $ZnCO_3$

COMP.—Zinc may be replaced to at least 50 per cent by iron (such a type has been called *monheimite*) and to an unknown, but notable, amount by magnesium, cobalt, manganese, calcium, cadmium and copper.

PHYS. CHAR.—Crystals very rare and imperfect; usually in incrustations. H. = 4.5. G. = 4.3–4.4 (pure). F. = 7. Soluble in HCl with effervescence.

OPT. PROP.—Uniaxial negative with extreme birefringence. On crystals[17] with 97.34 $ZnCO_3$ and 0.93 $FeCO_3$, $N_o = 1.849$, $N_e = 1.621$, $N_o - N_e = 0.228$.

Color white, grayish, greenish, brownish, blue. Colorless in section.

ALTER.—Changes to hemimorphite; in part to limonite; it may be replaced by quartz, etc.

OCCUR.—Found in veins and in beds usually associated with sphalerite and galena; also with copper and iron ores. It is found in calcareous rocks and in the oxide zone of ore deposits.

DIAG.—Differs from the other members of the calcite group in mode of occurrence, alteration, and associated minerals; also in the presence of zinc.

Spherocobaltite ($CoCO_3$) is trigonal with perfect $10\bar{1}1$ cleavage. H. = 3–4. G. = 4.1. F. = 7. Slowly soluble in cold acid. Uniaxial negative with $N_o = 1.855$, $N_e = 1.600$, $N_o - N_e = 0.255$. Color rose-red, black; colorless in section. Found in ore deposits. Rare.

ARAGONITE GROUP

The minerals of the aragonite group are carbonates of divalent metals having orthorhombic symmetry. The crystals are commonly twinned on 110 to pseudohexagonal forms. The minerals all have cleavages parallel to 110 and 010, and a hardness of 3 to 4; their optic properties are very similar, all having the acute negative bisectrix parallel to *c*, and a small optic angle. The chief minerals of the group are the following:

Aragonite	$a : b : c = 0.6228 : 1 : 0.7204$	$CaCO_3$
Cerussite	$a : b : c = 0.6102 : 1 : 0.7232$	$PbCO_3$
Strontianite	$a : b : c = 0.6090 : 1 : 0.7237$	$SrCO_3$
Witherite	$a : b : c = 0.5949 : 1 : 0.7413$	$BaCO_3$

The mutual solubilities of these molecules are unknown, but apparently considerable, at least between $CaCO_3$ and $BaCO_3$. For example, *bromlite* or *alstonite* is said to be an isomorphous mixture of aragonite and witherite in a ratio varying from 1 : 1 to 2 : 1.

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[17] E. D. Mountain: *Mineral. Mag.*, XXI, 1926, p. 51. For crystals with 90.4 $ZnCO_3$ and 3.5 $MnCO_3$ Gaubert reported (*C. R.*, CLXIV, 1917, p. 46) $N_o = 1.782$, $N_e = 1.612$, and (*Bull. Soc. Fr. Min.*, XLII, 1919, p. 99) $N_o = 1.872$, $N_e = 1.612$.

ARAGONITE ORTH. $a : b : c = 0.6228 : 1 : 0.7204$ $CaCO_3$

PHYS. CHAR.—Crystals commonly acicular with distinct 010 and 110 cleavages. Cleavages not conspicuous in thin section because the mineral is apt to be in fibrous or acicular aggregates. Twinning on 110 of the cyclic type producing pseudohexagonal forms. H. = 3.5–4. G. = 2.94. F. = 7, but falls to a white powder on account of dissociation to CaO and CO_2, complete at 900° C. Fusible at 1290° C. under pressure of 110 atmospheres of CO_2. Readily soluble in cold dilute acid with effervescence.

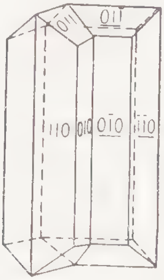

FIG. 51.—Aragonite twinned on 1$\bar{1}$0.

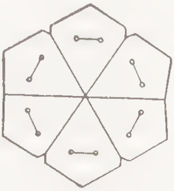

FIG. 52.—Cross-section of pseudo-hexagonal twin of aragonite.

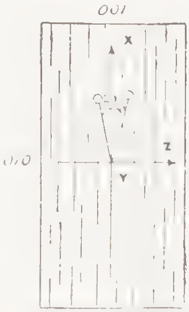

FIG. 53.—Optic orientation of aragonite.

OPT. PROP.—The plane of the optic axes is parallel to 100; the negative acute bisectrix X is normal to the base. The refringence is visibly different in varying positions in most sections, ranging from low to high. The birefringence is extreme, producing iridescent colors, due to slight variations in thickness, similar to those of calcite. The elongation is negative.

$(-)2V = 18°\ 11'$ $(2E = 30°\ 52'$ Na), $\rho < v$ weak.

$N_g = 1.685, N_m = 1.681, N_p = 1.530, N_g - N_p = 0.155.$

Colorless, white or stained. Colorless in section.

INVER.—Aragonite, alone or with calcite, is obtained by precipitation from aqueous solution at ordinary temperatures. It inverts to calcite in a few days at 100° C., and more rapidly at higher temperature.

OCCUR.—Many shells are composed of aragonite, which is not rare in lake deposits, ore deposits, and in various rocks, especially as an alteration product.

DIAG.—Differs from calcite in its biaxial character and less distinct cleavages; in fibrous forms the cleavages in aragonite are parallel to the elongation, while in calcite they are oblique. Aragonite differs from witherite, strontianite and cerussite in the position of the optic plane.

Bromlite $\{(Ca,Ba,Sr)CO_3\}$ is intermediate in type between aragonite and witherite, and may contain 5 to 10 per cent of $SrCO_3$. It has $a : b : c = 0.583 : 1 : 0.719$ and $G. = 3.71$. Crystals with $CaO = 17.6$, $BaO = 48.54$, $SrO = 4.25$, $CO_2 = 29.41$ have[18] $(-)\ 2V = 7° 14'$, $N_g = 1.671(7)$, $N_m = 1.671(0)$, $N_p = 1.5261$, $N_g - N_p = 0.145(6)$. Found in lead deposits in England. Rare.

CERUSSITE ORTHORHOMBIC $a : b : c = 0.6102 : 1 : 0.7232$ $PbCO_3$

PHYS. CHAR.—Crystals 010 tablets, brachydomatic, or pyramidal. Twinning on 110 common; on 130 less common. Distinct 110 and 021 cleavages. $H. = 3-3.5$. $G. = 6.57$. $F. = 1.5$. Soluble in dilute HNO_3 with effervescence.

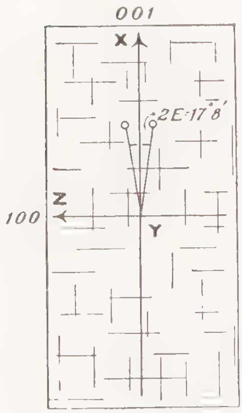

FIG. 54.—Optic orientation of cerussite.

OPT. PROP.—The optic plane is parallel to 010 and the acute negative bisectrix X is normal to 001. The dispersion is marked with $\rho > v$. The optic angle decreases with decreasing temperature, becoming uniaxial at $-119°$ C. and biaxial with $2E = 11°$ in 100 at $-190°$ C. On very pure cerussite Dubigk[19] obtained: $(-)2V = 8° 34'$ Na, $N_g = 2.076$, $N_m = 2.074$, $N_p = 1.803$, $N_g - N_p = 0.273$. The mineral is uniaxial at 15° C. for light of 415 $\mu\mu$ wave length.[20]

Color white, gray, grayish black. Colorless in section.

OCCUR.—Chiefly in the oxide zone of lead ore deposits.

DIAG.—Differs from anglesite in extreme birefringence; from aragonite, witherite and strontianite in very high relief and extreme birefringence.

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[18] St. Kreutz: *N. Jahrb. Min.*, 1910, II, p. 12.

[19] *N. Jahrb. Min. Beil. Bd.*, XXXVI, 1913, p. 236.

[20] P. Sève: *Bull. Soc. Fr. Min.*, XLII, 1920, p. 9.

STRONTIANITE ORTH. $a : b : c = 0.6090 : 1 : 0.7237$ $SrCO_3$

PHYS. CHAR. —Crystals commonly acicular; twinning on 110 common both in lamellar and pseudohexagonal groups. Nearly perfect 110 cleavages. H. = 3.5–4. G. = 3.71. F. = 1497° C.[21] after swelling and sprouting. Soluble in HCl with effervescence.

OPT. PROP.—The optic plane is parallel to 010 and the acute negative bisectrix X is normal to 001. $(-)2V = 10° 36'$, $\rho < v$ very weak. $N_g = 1.666$ Na, $N_m = 1.664$, $N_p = 1.516$, $N_g - N_p = 0.150$.

Color pale to apple green, white, yellow. Colorless in section.

INVER.—There is a reversible inversion to a hexagonal form at 929° C.; this form fuses at 1497° C.

OCCUR.—In veins and geodes, and concretions in limestone, etc. Uncommon.

DIAG.—Differs from aragonite in having excellent 110 cleavages, in density, and in the position of the optic plane.

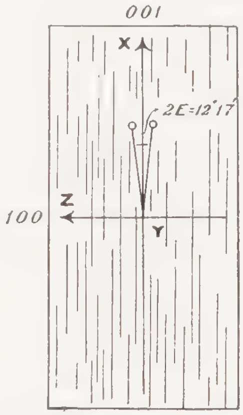

FIG. 55.—Optic orientation of strontianite.

WITHERITE ORTH. $a : b : c = 0.5949 : 1 : 0.7413$ $BaCO_3$

PHYS. CHAR.—Crystals pseudohexagonal pyramids by twinning on 110. Distinct 010 and imperfect 110 and 012 cleavages. H. = 3.5. G. = 4.3. F. = 2.5–3, giving yellowish green flame color. But under pressure preventing dissociation $BaCO_3$ fuses[21] at 1740° C. Soluble in dilute HCl with effervescence.

OPT. PROP.—The optic plane is parallel to 010 and the acute negative bisectrix X is normal to 001. $(-)\ 2V = 16°$, $\rho > v$ very weak. $N_g = 1.677$, $N_m = 1.676$, $N_p = 1.529$, $N_g - N_p = 0.148$ (Mallard[22] .

Color white, yellowish, grayish. Colorless in section.

INVER.—Inverts[21] at 811° C. to a hexagonal form, which inverts at 982° C. to an isometric form, which fuses at about 1740° C.

OCCUR.—Usually associated with ores in veins. Rare.

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[21] H. E. Boeke: *N. Jahrb. Min.*, 1914, I, p. 9.

[22] *Bull. Soc. Fr. Min.*, XVIII, 1895, p. 8.

DIAG.—Distinguished by high density and yellowish green flame color.

Barytocalcite ($CaBaC_2O_6$) is monoclinic with $a : b : c = 0.772 : 1 : 0.625$, $\beta = 73° 52'$; crystals elongated in a diagonal direction by extension of $\bar{1}21$ and $\bar{1}51$; 100 faces vertically striated. Perfect 110 and imperfect 001 cleavages. The three cleavages make a pseudorhombohedron nearly like that of calcite. H. = 4. G. = 3.65. F. = difficult. Optic plane normal to 010; $X \wedge c = +64° 22'$. $(-)\ 2V = 15°$, $\rho > v$, weak. $N_g = 1.686$, $N_m = 1.684$, $N_p = 1.525$, $N_g - N_p = 0.161$ Na.[22] Color white, gray, greenish, yellowish. Found in limestone with barite and fluorite. Very rare.

3. ANHYDROUS BASIC CARBONATES OF DIVALENT BASES

Hydrocerussite $\{Pb(OH)_2 \cdot 2PbCO_3\}$ is hexagonal with $c = 1.419$; crystals thin basal plates with perfect 0001 cleavage. H. = 3.5. G. = 6.80. F. = 1.5. Soluble in acid with effervescence. Uniaxial negative with $N_o = 2.09$,[23] $N_e = 1.94$, $N_o - N_e = 0.15$. Colorless. Found as a coating on native lead and in cavities in galena. Rare.

AZURITE Monoclinic $Cu(OH)_2 \cdot 2CuCO_3$

$$a : b : c\ ^{24} = 0.856 : 1 : 0.884,\ \beta = 87° 35'$$

PHYS. CHAR.—Crystals varied and complex, thus, tabular parallel to 001 or 101, prismatic, elongated parallel to b or pseudorhombohedral. Twinning not common. Perfect 021 and distinct 100 cleavages. H. = 3.5–4. G. = 3.80. F. = 3. Soluble in acid with effervescence.

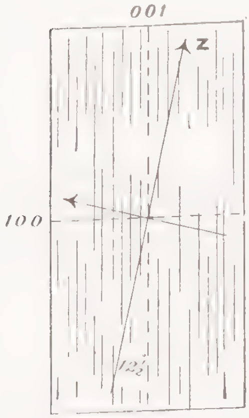

FIG. 56.—Optic orientation of azurite.

OPT. PROP.—The optic plane is normal to 010; the positive acute bisectrix Z makes an angle of $-12\frac{1}{2}°$ with c, with distinct horizontal dispersion. $(+)\ 2V = 68°$, $\rho > v$, notable. $N_g = 1.838$, $N_m = 1.758$, $N_p = 1.730$, $N_g - N_p = 0.108$.

Color azure to Berlin blue with X and Y = clear blue, Z = dark azure to purplish blue, $X < Y < Z$. Absorption and pleochroism distinct in *thick* sections.

ALTER.—Changes rather easily to malachite; rarely to cuprite and native copper.

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[23] H. E. Merwin: *Proc. Am. Soc. Test. Mat.*, XVII, 1917, p. 21. See also *Mineral. Mag.*, XX, p. 80.

[24] C. Palache and L. W. Lewis: *Am. Mineral.*, XII, 1927, p. 99.

MALACHITE Monoclinic $Cu(OH)_2 \cdot CuCO_3$

$a : b : c = 0.881 : 1 : 0.401, \beta = 61° 50'$

Comp.—In *cuprozincite*[25] about one-fifth of the copper is replaced by zinc.

Phys. Char.—Crystals acicular to fibrous prismatic in tufts, etc. Twinning common on 100. Perfect 001 and distinct 010 cleavages. H. = 4. G. = 4.0. F. = 2. Soluble in HNO_3 with effervescence.

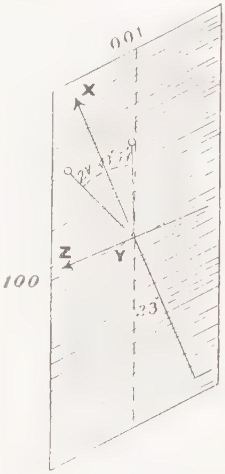

Fig. 57.—Optic orientation of malachite.

Opt. Prop.—The optic plane is parallel to 010; the negative acute bisectrix X makes an angle of $+ 23\frac{1}{2}°$ with c or 85° with the cleavage 001; this angle $(X \wedge c)$ is 21° to 23° in cuprozincite. Weak inclined dispersion with $\rho < v$, distinct, in air, though $\rho > v$, large, in the crystal.

$(-)$ $2V = 43°$, $N_g = 1.909$, $N_m = 1.875$, $N_p = 1.655$, $N_g - N_p = 0.254$ (Larsen), $N_p = 1.703$ (Perrier[26]).

Color green with X = nearly colorless, Y = yellowish green, Z = deep green.

Occur.—Common in the oxide zone of copper deposits, especially those in limestone areas.

Diag.—Differs from atacamite in having inclined extinction of fibers and extreme birefringence; further, in malachite, the best cleavage is across the elongation and a little oblique to the acute bisectrix, while a second cleavage usually shows twinning on 100 with extinction at 23° and an optic normal figure; atacamite and brochantite have only one distinct cleavage (010) which is parallel to the elongation and normal to the acute bisectrix.

HYDROZINCITE Monoclinic $3Zn(OH)_2 \cdot 2ZnCO_3$

Comp.—Hydrozincite is usually amorphous, but crystals[27] seem to have the composition given. The zinc may be replaced by copper in large amounts; thus in *aurichalcite* with Zn : Cu = 2 : 1 to 1 : 2[25], $a : b : c$[28] $= ? : 1 : 1.657, \beta = 84° 15'$. Biehl[25] argues that hydrozincite, aurichalcite and malachite belong to a single isomorphous series, but the optic properties are not easily reconciled with this view.

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[25] F. K. Biehl: *Mineral. Abst.*, I, 1921, p. 203.

[26] *Min. Abst.*, II, 1924, p. 286.

[27] Ford and Bradley: *Amer. Jour. Sci.*, CXCII. 1916, p. 59.

[28] G. D'Achiardi: *Att. Soc. Tosc. Nat. Sci. Pisa Mem.*, XVI., 1898, p. 3; Doelter: *Hdb. Mineral Chem.*, I, p. 474.

Phys. Char.—Crystals minute thin blades parallel to 100 (or 001) elongated parallel to c (or a); also vertical fibers (?). Perfect 100 (or 001) cleavage. H. = 2–2.5. G. = 3.6. F. = 7. Soluble in HCl with effervescence.

Opt. Prop.—The optic plane is normal to 010 and Z makes a moderate angle with c (or a).

$$\begin{array}{l} (-)\ 2V = 40^\circ, \\ \rho < v, \text{ distinct} \end{array} \left\{ \begin{array}{llll} N_g = 1.73 & N_m = ? & N_p = 1.65 & N_g - N_p = 0.08 \\ N_g = 1.73 & N_m = ? & N_p = 1.63 & N_g - N_p = 0.10 \\ N_g = 1.750 & N_m = 1.736 & N_p = 1.640 & N_g - N_p = 0.11 \end{array} \right.$$

The third set of indices suggests variation toward aurichalcite.

Color white, grayish, yellowish. Colorless in section.

Occur.—In oxide zone of zinc deposits with smithsonite, etc. Uncommon.

Aurichalcite $\{3(Zn, Cu)(OH)_2 \cdot 2(Zn,Cu)CO_3\}$ has the same characters as hydrozincite except that G. = 3.64 +, (−) 2V = very small, $\rho < v$, strong. $N_g = 1.744$, $N_m = 1.740$, $N_p = 1.655$, $N_g - N_p = 0.089$; Y nearly normal to cleavage (100) and Z nearly parallel with the elongation (Larsen); plates on edge have an extinction angle of 41°–42° (Shannon [29]). Color pale green or blue with X = nearly colorless, Y and Z = pale greenish. Found in the oxide zone of zinc-copper deposits, in some cases an alteration product of malachite. Uncommon.

Rosasite [30] is said to be an orthorhombic mineral of the composition of aurichalcite. It breaks into rectangular plates which have parallel extinction and negative elongation. N_1 along the length = 1.71, N_2 across the length = 1.745. Rare.

4. HYDROUS CARBONATES OF DIVALENT BASES [31]

Artinite $\{MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O\}$ is orthorhombic in fibrous aggregates. H. = 2. G. = 2.03. If fibers are taken as prismatic, Y = c and optic axes are nearly normal to prism faces. (−) 2V = 71°±. $N_g = 1.557$, $N_m = 1.534$, $N_p = 1.489$, $N_g - N_p = 0.068$. Colorless. Found in an asbestos quarry. Very rare.

Hydromagnesite [32] $\{3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O\}$ is monoclinic with $a : b : c = 1.137 : 1 : 0.903$, $\beta = 65^\circ\ 52'$. Crystals 100 tablets elongated parallel to c; in tufts. Perfect 010 cleavage, and distinct 100 parting or cleavage. Constant twinning on 100, often lamellar. H. = 3.5. G. = 2.16. F. = 7. Soluble in acid with effervescence. Optic plane and Z normal to 010; $Y \wedge c = -42^\circ\ 51'$. (+) 2V = moderate. $N_g = 1.545$, $N_m = 1.527$, $N_p = 1.523$, $N_g - N_p = 0.022$ (Rogers); $N_g = 1..540$, $N_m = 1.530$, $N_p = 1.527$, $N_g - N_p = 0.013$ (Larsen). Index parallel to $c = 1.526$. Colorless. Found chiefly in serpentine, as an alteration product; also with brucite.

Lansfordite $(MgCO_3 \cdot 5H_2O)$ is monoclinic [33] with $a : b : c = 1.632 : 1 : 0.968$, $\beta = 78^\circ\ 11'$. Crystals stalactitic with distinct 001 cleavage. H. = 2.5. G. = 1.73. F. = 7. Soluble in acid with effervescence. Optic plane normal to 010. $Z \wedge c$ = small.

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[29] *U. S. Nat. Mus. Bull.*, 131, 1926, p. 266.

[30] C. Perrier: *Min. Abst.*, II, 1924, p. 240.

[31] "*Remingtonite*" $(CoCO_3 \cdot nH_2O?)$ omitted as suggested by Shannon (*Am. Mineral.*, IX, 1924, p. 208).

[32] A. F. Rogers: *Am. Jour. Sci.*, CCVI, 1923, p. 37.

[33] G. Césaro: *Bull. Acad. Roy. Cl. Sci. Bruxelles,* 1910, p. 234.

(+) $2V = 60° \; 37'$; $N_g = 1.502$, $N_m = 1.476$, $N_p = 1.456$, $N_g - N_p = 0.046$ Na.[34] Alters promptly in air to nesquehonite. Found as stalactites in coal mines. Very rare.

Zaratite ($3NiO \cdot CO_2 \cdot nH_2O$?) is amorphous, often banded in crusts, etc. H. = 3. G. = 2.6 ±. F. = 7. Soluble in HCl with effervescence. Isotropic with N = 1.56 to 1.61. Also weakly birefringent [34a] with parallel extinction and positive elongation, and N = 1.565 ±; also N = 1.589. Emerald green color. Found with chromite in serpentine, etc. Rare.

5. CHLOROCARBONATES AND FLUOCARBONATES

Northupite ($Na_3MgClC_2O_6$) is isometric and octahedral without cleavage. H. = 4. G. = 2.38. F. = 1 with frothing. Soluble in acid with effervescence. Isotropic with N = 1.5144 Na. Also abnormal birefringence [35] with twinning. Colorless. Found in clay at a depth of 450 feet at Borax Lake, Calif. Very rare.

Phosgenite ($Pb_2Cl_2CO_3$) is tetragonal with $c = 1.088$. Crystals prismatic, or basal tablets, or acute pyramidal. Distinct 110, 100 and less distinct 001 cleavages. H. = 3. G. = 6.0–6.3. F. = 1. Soluble in dilute HNO_3 with effervescence. Uniaxial positive with N_o[36] $= 2.118$, $N_e = 2.145$, $N_e - N_o = 0.027$. Color white, gray, yellow. Colorless in section. Found in lead deposits, as at Laurium, Greece. Very rare.

Bastnäsite $\{(Ce,La,Di)FCO_3\}$ is hexagonal with $c = 0.68$. Crystals prismatic with basal parting. H. = 4. G. = 5.0. F. = 7. Difficultly soluble in H_2SO_4 with effervescence. Uniaxial positive with $N_o = 1.717$, $N_e = 1.818$, $N_e - N_o = 0.101$ (Larsen); $N_o = 1.722$, $N_e = 1.824$, $N_e - N_o = 0.102$ Na (P. Geijer).[37] Color yellow, reddish, brown with weak pleochroism. Found in pegmatite. Rare.

Parisite $\{Ca(Ce,La,Di)_2F_2C_3O_9\}$ is hexagonal with $c = 1.937$. Crystals barrel-shaped, horizontally striated with perfect basal cleavage developed by alteration. H. = 4.5. G. = 4.42. F. = 7. Soluble in HCl with effervescence. Uniaxial positive with [38] $N_o = 1.672$, $N_e = 1.771$, $N_e - N_o = 0.099$. Colorless or yellow with X = light yellow, Z = golden yellow. May show brown pigment in zones. Found in pegmatite. Rare.

Cordylite $\{Ba(Ce,La,Di)_2F_2C_3O_9\}$ is hexagonal with $c = 3.387$. Crystals prismatic with distinct basal cleavage. H. = 4.5. G. = 4.31. F. = 7, but decrepitates and turns brown. Soluble in HCl with effervescence. Uniaxial negative with $N_o = 1.760$, $N_e - 1.577$, $N_o - N_e = 0.183$. May be zoned in vertical sections. Color wax-yellow with X = brownish yellow, Z = greenish-yellow. Found in pegmatite in Greenland. Very rare.

6. CARBONATES OF TRIVALENT BASES

Bismutospherite $\{(BiO)_2CO_3\}$ is in fibrous concretions and basal tablets. H. = 3–3.5. G. = 7.3–7.4. F. = 1.5. Soluble in acid with effervescence. Uniaxial negative with $N_o = 2.13$, $N_e = 1.94$, $N_o - N_e = 0.19$. Color yellow, green, brown. Found in veins. Rare.

Lanthanite $\{(La,Di,Ce)_2(CO_3)_3 \cdot 8H_2O\}$ is orthorhombic with $a : b : c = 0.94 : 1 : 0.89$. Crystals thin basal plates with perfect 001 cleavage. H. = 3. G. = 2.6–2.74. F. = 7.

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[34] H. Leitmeier: *N. Jahrb. Min. Beil. Bd.*, XL, 1916, p. 655.

[34a] F. Slavik: *Am. Mineral*, XI, 1926, p. 279.

[35] Zepharovich: *Zt. Angew. Chem.*, LXXXVII, 1893, H. 15.

[36] H. Baumhauer: *Zeit. Kryst.*, XLVII, 1909, p. 9.

[37] *Sver. Geol. Undersök. Aarsb.*, 14, 1921, No. 6.

[38] E. Quercigh: *Rend. Accad. Lincei Rom.*, XXI, 1912, p. 581. *Zeit. Kryst.*, LV, 1915, p. 273.

Soluble in acid with effervescence. Optic plane is 100; X = c. (−) $2V = 62°$, $\rho < v$, weak. $N_g = 1.613$, $N_m = 1.587$, $N_p = 1.52$, $N_g - N_p = 0.093$. Color white. Found in zinc and iron ore deposits. Very rare.

Tengerite is a hydrous carbonate of yttrium, etc., of uncertain formula. It is fibrous or powdery. Soluble in acid with effervescence. Axis X parallel to elongation. (+) 2V = large. $N_g = 1.585$, $N_m = 1.57$, $N_p = 1.555$, $N_g - N_p = 0.030$. Color white. Found with gadolinite. Very rare.

Bismutite is a hydrous basic bismuth carbonate, fibrous or earthy. H. = 4. G. = 7.0 ±. F. = 1.5. Soluble in HNO_3 with effervescence. Axis Z parallel to fibers. (−) 2V = medium, $N_m = 2.15$ to 2.28, $N_g - N_p = 0.05 \pm$. Also in part isotropic. Color white, green, yellow. Found in ore deposits. Rare.

7. CARBONATES OF TETRAVALENT BASES

Rutherfordite (UO_2CO_3) is orthorhombic (?), finely fibrous. Soft. G. = 4.82. Soluble in acid with effervescence. Optic sign unknown. $N_g = 1.80$, $N_m = 1.75 \pm$, $N_p = 1.72$, $N_g - N_p = 0.08$. Color yellow, earthy. An alteration product of uraninite. Rare.

Schroeckingerite is hydrous uranium carbonate. Crystals are monoclinic 010 laths with very perfect 010 and distinct 100 cleavages. Lamellar twinning on 100. Soft. Optic plane is normal to 010; $Z \wedge c = 41° \pm$ with extreme crossed dispersion so that sections normal to X give no extinction and very abnormal interference colors. (−) $2E = 70°$ (120°), $2V = 40°$ (57°), $\rho > v$, very strong. $N_g = 1.690$ (1.706), $N_m = 1.687$ (1.698), $N_p = 1.658$ (1.660), $N_g - N_p = 0.032$ (0.046). Color greenish to yellow with X = colorless, Y and Z = canary yellow. Alteration product of uranium minerals. Very rare.

8. CARBONATES OF DIVALENT AND MONOVALENT BASES

Pirssonite ($Na_2CaC_2O_6 \cdot 2H_2O$) is orthorhombic with $a : b : c = 0.566 : 1 : 0.902$. Crystals prismatic with no cleavage. H. = 3-3.5. G. = 2.35. F. = 2. Soluble in cold acids with effervescence. Optic plane is 001; Z = b. (+) $2V = 33°$, $\rho < v$, weak. $N_g = 1.575$ Na, $N_m = 1.509$, $N_p = 1.504$, $N_g - N_p = 0.071$ Na. Colorless. Found with gaylussite in lake deposits. Rare.

Gaylussite ($Na_2CaC_2O_6 \cdot 5H_2O$) is monoclinic with $a : b : c = 1.490 : 1 : 1.444$, $\beta = 78° 27'$. Crystals elongated parallel to a or wedge-shaped. Perfect 110 and imperfect 001 cleavages. H. = 2-3. G. = 1.94. F. = 1.5. Soluble in acid with effervescence. Optic plane is normal to 010; $Z \wedge c = -14° 48'$ Li, $-13° 8'$ blue. (−) $2E = 52°$, $2V = 34°$, $\rho < v$ strong. $N_g = 1.523$, $N_m = 1.516$, $N_p = 1.443$, $N_g - N_p = 0.080$ Na. Colorless. Found in lake deposits. Uncommon.

9. CARBONATES OF TRIVALENT AND MONOVALENT BASES

Dawsonite {$NaAl(OH)_2CO_3$} is orthorhombic with $a : b : c = 0.648 : 1 : 0.534$. Crystals acicular parallel to c or bladed. Perfect 110 cleavage. H. = 3. G. = 2.4. F. = 4.5-5. Soluble in HCl with effervescence. Optic plane is 001; X = a. (−) $2E = 146°$, $2V = 77°$, $\rho < v$ weak. $N_g = 1.596$, $N_m = 1.542$, $N_p = 1.466$, $N_g - N_p = 0.130$. Color white. Found as an alteration product. Very rare.

10. CARBONATES OF TRIVALENT AND DIVALENT BASES

Hydrotalcite ($6MgO \cdot Al_2O_3 \cdot CO_2 \cdot 12H_2O$) is hexagonal in basal plates with perfect basal cleavage. H. = 2. G. = 2.06. F. = 7. Soluble in acid with effervescence. Uniaxial negative with $N_o = 1.512$, $N_e = 1.498$, $N_o - N_e = 0.014$. Color white with pearly luster. Found in ore deposits and schists. Rare.

Pyroaurite ($6MgO \cdot Fe_2O_3 \cdot CO_2 \cdot 12H_2O$) is hexagonal in basal plates or fibrous. $c = 3.607$. Perfect basal cleavage. H. = 2-3. G. = 2.07. F. = 7. Soluble in acid with effervescence. Uniaxial negative with $N_o = 1.565 \pm$, $N_o - N_e = 0.01$ (Larsen); $N = 1.55$ (Foshag [39]). Color brown to white with X = colorless, Z = yellow red. *Brugnatellite* is very similar, but contains less iron and has $N_o = 1.540$, $N_e = 1.510$, $N_o - N_e = 0.030$. ($N_o = 1.536$, $N_o - N_e$ = very weak, Foshag [39]; $N_o = 1.536$, Artini.[40]) Color flesh pink. Found in iron ore and in serpentine. Rare.

Stichtite ($6MgO \cdot Cr_2O_3 \cdot CO_2 \cdot 12H_2O$) is hexagonal in basal plates with perfect basal cleavage. H. = 1.7. G. = 2.16. F. = 7. Soluble in acid with effervescence. Uniaxial negative with $N_o = 1.542$, $N_e = 1.516$, $N_o - N_e = 0.026$. Color lilac with $X < Z$, weak. Found as an alteration product of serpentine. Rare.

Ancylite ($3SrO \cdot 2Cr_2O_3 \cdot 7CO_2 \cdot 5H_2O$) is orthorhombic [41] with $a : b : c = 0.916 : 1 : 0.917$. Crystals pyramidal without cleavage. H. = 4.5. G. = 3.95. F. = 7. Soluble in acid with effervescence. Optic orientation [42] perhaps $X = a$, $Y = b$, $Z = c$. (−) 2V = 66° (calc. [42]), $N_g = 1.735$, $N_m = 1.700$, $N_p = 1.625$, $N_g - N_p = 0.110$. Color brown, greenish, orange. Inclusions of acmite. Found with albite in Greenland. Very rare.

Ambatoarinite [43] $\{5SrO \cdot 5(Ce,La,Di)_2O_3 \cdot 17CO_2?\}$ is perhaps the same as ancylite; it is orthorhombic with a prism angle of 92°. Soluble in cold HCl. Optic plane is 010. $X = c$. (−) 2V = ?. $N_p > 1.658$, $N_g - N_p = 0.08$. Color black or red. A pneumatolytic product with celestite and monazite. Very rare.

11. CARBONATES OF TETRAVALENT AND DIVALENT BASES

Uranothallite ($Ca_2UC_4O_{12} \cdot 10H_2O$) is orthorhombic with $a : b : c = 0.954 : 1 : 0.783$. Crystals indistinct, in crusts with distinct 100 cleavage. H. = 2.5 3. F. = 7. Soluble in acid with effervescence. Axis $X = a$. (+) 2V = 37°–42°, $\rho > v$ weak. $N_g = 1.539$, $N_m = 1.503$, $N_p = 1.500$, $N_g - N_p = 0.039$. Color green. *Liebigite* is probably a synonym.[44] An alteration product of uraninite. Rare.

Voglite (hydrous carbonate of V, Ca, Cu) is triclinic (?) in scales. Soft. F. = 7. Soluble in acid with effervescence. Axis X nearly normal to scales in which $Z' \wedge$ elongation = 33°. (+) 2V = 60°, $\rho < v$, very strong. $N_g = 1.564$, $N_m = 1.547$, $N_p = 1.541$, $N_g - N_p = 0.023$. Lamellar twinning parallel to scales. Color emerald green with X and Y = deep bluish green, Z = pale yellowish. An alteration product of uraninite. Rare.

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[39] *Proc. U. S. Nat. Mus.*, LVIII, 1920, p. 147.

[40] *Min. Abst.*, II, 1924, p. 240.

[41] G. Flink: *Med. Grönl.*, XXIV, 1901, p. 49. A. E. Fersman: *Am. Mineral*, XI, 1926, p. 289.

[42] S. G. Gordon: personal communication, Nov. 24, 1924 and Dec. 17, 1924.

[43] A. Lacroix: *Bull. Soc. Fr. Min.*, XXXVIII, 1915, p. 265. *Minéral. Madag.*, I, 1922, p. 300.

[44] E. S. Larsen: *Am. Mineral*, II, 1917, p. 87.

12. NATURAL COMPOUNDS INVOLVING OTHER CARBON ACIDS

Mellite ($Al_2C_{12}O_{12}\cdot 18H_2O$) is tetragonal with $c = 0.746$. Crystals pyramidal with indistinct 111 cleavage. H. = 2–2.5. G. = 1.6. Decomposed by boiling water; soluble in HNO_3. Uniaxial negative with $N_o = 1.539$ D, $N_e = 1.511$, $N_o - N_e = 0.028$. Color honey yellow, reddish, white. Found in brown coal. Uncommon.

Flagstaffite[45] ($H_{20}C_{10}O_2\cdot H_2O$) or *terpin hydrate* is orthorhombic with $a : b : c = 0.807 : 1 : 0.476$. Crystals prismatic with imperfect 110 cleavage. Very soft. G. = 1.09. F. = 116° C. Soluble in warm alcohol. Optic plane is 010; $Z = a$. (+) $2V = 77° 27'$, $\rho > v$, weak. $N_g = 1.524$ Na, $N_m = 1.512$, $N_p = 1.505$, $N_g - N_p = 0.019$ Na. Colorless. Found in cracks of a log in Arizona. Rare.

Humboldtite ($FeC_2O_4\cdot 2H_2O$) or *oxalite*,[46] is orthorhombic with $a : b : c = 0.773 : 1 : 1.104 \pm$. Crystals prismatic with perfect 110 and distinct 100 and 010 cleavages. H. = 2. G. = 2.28. Soluble in acid. Optic plane is 010; $Z = c$. (+) $2V$ = large. N_g 1.692, $N_m = 1.561$, $N_p = 1.494$, $N_g - N_p = 0.198$. Color yellowish with X = pale yellowish green, Y = pale greenish yellow, Z = intense yellow. Found in brown coal and black shales. Rare.

Oxammite $\{(NH_4)_2C_2O_4\cdot H_2O\}$ is orthorhombic with $a : b : c = 0.78 : 1 : 0.37$. Crystals prismatic or 100 tablets; sphenoidal, with imperfect 001 cleavage. H. = soft. G. = 1.48 ±. F. = easy. Soluble in water. Optic plane is 100; $X = c$. (−) $2V = 62°$, $\rho < v$, distinct. The artificial salt has: $N_g = 1.595$ Na, $N_m = 1.547$, $N_p = 1.438$, $N_g - N_p = 0.157$. Color white. Found in guano. Rare.

Whewellite ($CaC_2O_4\cdot H_2O$) is monoclinic with $a : b : c = 0.87 : 1 : 1.37$, $\beta = 72° 42'$. Crystals complex; twinning on 101; 001, 010, 110 and 101 cleavages. H. = 2.5. G. = 2.23. F. = 7. Soluble in acid. Optic plane[47] normal to 010; $Z \wedge c = + 29°$. (+) $2E = 84°$, $\rho < v$, weak. $N_g = 1.650$, $N_m = 1.555$, $N_p = 1.490$, $N_g - N_p = 0.160$. Colorless. Found in calcite veins in coal; also in plant tissues. Rare.

Succinite is a fossil *resin* or *amber*; it is amorphous with H. = 2–2.5. G. = 1.06–1.075. F. = 250°–300° C. Only partly soluble in alcohol. Isotropic with N = 1.53 (Dahms[48]); 1.543 (Larsen). Color amber yellow. By weathering, G. increases to 1.09 and N decreases to 1.51 or even to 1.49. Not rare on coast of Prussia; of vegetable origin.

13. IODATES

Lautarite (CaI_2O_6) is monoclinic with $a : b : c = 0.633 : 1 : 0.646$, $\beta = 73° 38'$. Crystals prismatic with distinct 011 cleavage. H. = 4. G. = 4.59. F. = 1.5. Soluble in HCl. Optic plane is 010; $X \wedge c = 25°$. (+) $2V$ = nearly 90°, $\rho > v$. $N_g = 1.888$, $N_m = 1.840$, $N_p = 1.792$, $N_g - N_p = 0.096$. Colorless to yellow. Found in caliche of Peru. Rare.

14. NITRATES

Nitratite (*Soda Niter*—$NaNO_3$) is trigonal with $c = 0.828$, isomorphous with calcite. Perfect rhombohedral cleavage. H. = 1.5–2. G. = 2.27. F. = 1; deflagrates on heating. Deliquescent. Soluble in water. Uniaxial negative with extreme birefringence; $N_o = 1.585$, $N_e = 1.337$, $N_o - N_e = 0.248$. N'_e on the cleavage = 1.467. Color white. Found with gypsum, halite, etc., as a surface formation in desert regions. Rare.

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[45] F. N. Guild: *Am. Mineral*, V, 1920, p. 169, VI, 1921, p. 133.

[46] E. Manasee: *Rend. Accad. Lincei Rom*, 1910, XIX, (5a), p. 138.

[47] E. T. Wherry: *Jour. Wash. Acad. Sci.*, XII, 1922, p. 196.

[48] *Schrift. Naturf. Gesell. Danzig*, XI, pt. 4, 1906, p. 25.

Niter (*Saltpeter*—KNO_3) is orthorhombic with $a : b : c = 0.591 : 1 : 0.701$. Crystals equant or vertical acicular with perfect 011 and imperfect 010 and 100 cleavages. H. = 2. G. = 2.1. F. = 1. Deflagrates vividly on coal with violet flame color. Soluble in water. Optic plane is 100; $X = c$. $(-)\ 2V = 7°$, $\rho < v$, strong. $N_g = 1.506$ D, $N_m = 1.505$, $N_p = 1.335$, $N_g - N_p = 0.171$. Colorless. Becomes rhombohedral and uniaxial at 339° C. Found in caves and on the surface in desert regions. Rare.

Gerhardtite ($4CuO \cdot N_2O_5 \cdot 3H_2O$) is orthorhombic with $a : b : c = 0.922 : 1 : 1.156$. Crystals thick basal tablets with striated pyramid zones. Perfect 001 and distinct 100 cleavages. H. = 2. G. = 3.43. F. = 2 Soluble in dilute acid. Optic plane is 010; $Z = c$.[49] $(+)\ 2V =$ large, $\rho < v$ very strong. $N_g = 1.722$, $N_m = 1.713$, $N_p = 1.703$, $N_g - N_p = 0.019$. Color emerald green with X and Y = green, Z = blue. Found in copper ores. Very rare.

Nitromagnesite ($MgN_2O_6 \cdot nH_2O$) is monoclinic (?) fibrous. F. = easy. Soluble in water. Taste bitter. $(-)\ 2V = 5°$, $\rho < v$, weak. $N_g = 1.506$, $N_m = 1.506$, $N_p = 1.344$, $N_g - N_p = 0.162$. Colorless. Reported from caves with nitrocalcite, and on magnesian rocks. Artificial $MgN_2O_6 \cdot 6H_2O$ is monoclinic with $a : b : c = 0.519 : 1 : 0.970$, $\beta = 78° 4'$. Crystals long prismatic with perfect 110 cleavages at 54° 48′.

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[49] J. Thoreau: *Ann. Soc. Geol. Belg.*, XLVI, 1924, p. B 285; *Min. Abst.*, III, 1926, p. 53.

VI. BORATES

"Aluminates" and "ferrites," which are related chemically to borates, have been included among the oxides. Since the type of acid involved is uncertain in many cases, all the acids of boron are considered together and classified on the basis of the valence of the metals present.

1. BORATES OF MONOVALENT BASES

Kernite[1] ($Na_2B_4O_7 \cdot 4H_2O$) is orthorhombic with perfect prismatic cleavage at 71° 8′. H. = 3. G. = 1.95. Fuses to clear glass after swelling. Very slowly soluble in cold water. $Z = c$ (= elongation). (−?) 2V = nearly 90°. $N_g = 1.488$, $N_m = 1.472$, $N_p = 1.454$, $N_g - N_p = 0.034$. Colorless to white. Found at a depth of several hundred feet in borings in Kern Co., Calif.

BORAX Monoclinic $Na_2B_4O_7 \cdot 10H_2O$

$$a : b : c = 1.0995 : 1 : 0.5632, \beta = 73^\circ 25$$

Phys. Char.—Crystals prismatic, resembling pyroxene, twinning on 100. Perfect 100 and distinct 110 cleavages. H. = 2. G. = 1.70. Before the blowpipe borax enlarges and fuses at 1–1.5 to transparent glass. Soluble in water.

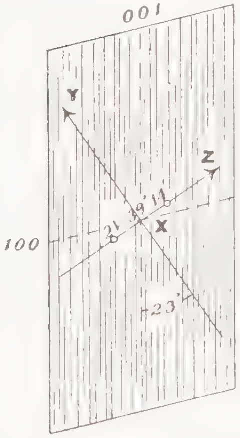

Fig. 58.—Optic orientation of borax.

Opt. Prop.—The optic plane is normal to 010; the axis Z makes an angle with c of − 55° 35′ Na (Tschermak), − 54° Na (Dufet) with strong crossed dispersion. By heating from 21° to 86° C. the optic plane is turned 3° 26′. (−) 2V = 39° 36′, $\rho > v$ distinct. $N_g = 1.472$ Na, $N_m = 1.469$, $N_p = 1.447$, $N_g - N_p = 0.025$. Color white.

Borax glass has N = 1.5147 Na.

Occur.—An abundant deposit of certain salt lakes, as in Thibet and California.

Diag.—The marked negative relief, moderate birefringence and strong dispersion are characteristic, especially when combined with the peculiar mode of occurrence.

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[1] W. T. Schaller: *Am. Mineral*, XII, 1927, p. 24.

Larderellite $\{(NH_4)_2B_8O_{13}\cdot 4H_2O\}$ is monoclinic in 100 tablets with perfect 001 cleavage. Plates have rhombic form with angle of 66°. Cleavage rhombs are pseudohexagonal. Soft. F. = easy. Soluble in water. $X = b$; Y near a; $Z \wedge c = 24°$. (+) $2V = 60° \pm$. $N_g = 1.561$, $N_m = 1.52$, $N_p = 1.509$, $N_g - N_p = 0.052$. Colorless. Found in Tuscan lagoons. Very rare.

2. ANHYDROUS BORATES OF DIVALENT BASES

Sussexite $\{H(Mn,Mg,Zn)BO_3\}$ is orthorhombic (?) and fibrous parallel to c. H. = 3. G. = 3.12. F. = 2 to black mass. Soluble in HCl. Axis X [1a] $= c$. $N_g = 1.704$, $N_p = 1.639$, $N_g - N_p = 0.065$. (−) 2V = small. $N_g = 1.712 \pm 0.003$, $N_m > 1.70$, $N_p = 1.6388$, $N_g - N_p = 0.073$.[2] Color white. Found at Franklin, N. J. Very rare.

Camsellite [3] ($HMgBO_3$?) is probably orthorhombic. Crystals lath-shaped. H. = 2.5. F. = easy. Optic plane parallel with laths and X parallel with elongation. (−) 2V = large.[4] $N_g = 1.649$, $N_m = 1.620 \pm .005$, $N_p = 1.575$, $N_g - N_p = 0.074$. Color white. Found in veins in serpentine with dolomite. Very rare.

Hambergite (Be_2OHBO_3) is orthorhombic with $a : b : c = 0.799 : 1 : 0.728$. Crystals prismatic, vertically striated. Perfect 010 and good 100 cleavages. H. = 7.5. G. = 2.35. F. = 7. Insoluble except in HF. Optic plane is 010; $X = a$. (+) $2V = 87° \ 7'$, $\rho < v$ distinct. $N_g = 1.631$ Na, $N_m = 1.591$, $N_p = 1.559$, $N_g - N_p = 0.072$ (Broegger [5]); $N_g = 1.627$, $N_m = 1.586$, $N_p = 1.553$, $N_g - N_p = 0.074$ (Lacroix [6]); (+) $2V = 87\frac{1}{2}°$, $N_g = 1.615$, $N_m = 1.58$, $N_p = 1.540$, $N_g - N_p = 0.075$ (Sokolow [7]). Color white. Found in pegmatite in Norway and Magadascar. Very vare.

3. HYDROUS BORATES OF DIVALENT BASES

Pinnoite ($MgB_2O_4\cdot 3H_2O$) is tetragonal with $c = 0.761$. Crystals prismatic, rare. H. = 3–4. G. = 2.29. F. = 3. Soluble in acid. Uniaxial positive [8] with $N_o = 1.565$, $N_e = 1.575$, $N_e - N_o = 0.010$. Color yellow. Found with boracite at Stassfurt. Rare.

Bechilite ($CaB_4O_7\cdot 4H_2O$) is a doubtful species.[9] A sample so labeled from Chile contains a negative uniaxial mineral with $N_o = 1.531$, $N_e = 1.510$, $N_o - N_e = 0.021$. Another sample from Italy is biaxial positive with $2V = 62° \pm$, with weak dispersion, $N_g = 1.542$, $N_m = 1.488$, $N_p = 1.470$, $N_g - N_p = 0.072$. Color white. Rare.

Szaibelyite ($2Mg_5B_4O_{11}\cdot 3H_2O$ with Fe_2O_3?) is acicular in nodular masses. H. = 3–4. G. = 2.76–3. Fuses. Optic data are conflicting. It is biaxial (Dana). It is uniaxial negative (Löw[10]) with $N_o = 1.65$, $N_e = 1.59$, $N_o - N_e = 0.06$. It has parallel extinction with $N = 1.60$ parallel to c, and $N = 1.575$ normal to c (F. Slavik[11]), and is therefore either positive or biaxial. It is uniaxial negative with $N_o = 1.650$, $N_e = 1.575$, $N_o - N_e = 0.075$ (Gillson and Shannon [12]). Color white, altering to yellow. Found in contact-altered limestone in Hungary and Nevada. Very rare.

[1a] E. Poitevin and H. V. Ellsworth: *Am. Mineral*, IX, 1924, p. 188.

[2] Measured by R. H. B. Jones and C. H. Stockwell under the writer's direction on material kindly supplied by Dr. Ellsworth. The mineral is therefore negative with small optic angle.

[3] H. V. Ellsworth and E. Poitevin: *Trans. Roy. Soc. Canada*, XV, 3, 1921, sect. 4, p. 1. A. S. Eakle (*Am. Mineral*, X, 1925, p. 100) gives the formula as $10\,(Mg,Fe)O\cdot 4B_2O_3\cdot SiO_2\cdot 5H_2O$, and G. = 2.60.

[4] Optic angle negative and large according to determination of N_m (given above) made by R. H. B. Jones and C. H. Stockwell under the writer's direction on material kindly supplied by Dr. Ellsworth.

[5] *Zeit. Kryst.*, XVI, 1890, p. 65.

[6] *Minéral. France*, IV, 1910, p. 347.

[7] *Ann. Inst. Mines St. Petersburg*, II, 1910, p. 394; *Zeit. Kryst.*, LII, 1913, p. 633.

[8] H. E. Boeke: *Centr. Mineral.*, 1910, p. 531.

[9] E. S. Larsen: *U. S. Geol. Survey Bull.* 679, 1921, p. 45.

Ascharite ($Mg_2B_2O_5 \cdot H_2O$) is orthorhombic (?) and fibrous. G. = 2.69. Nearly insoluble in water. Axis X parallel to fibers. (−) 2V = small. $N_g = 1.55$, $N_m = 1.55$, $N_p = 1.53$, $N_g - N_p = 0.02$. Color white. Found with boracite in lake deposits. Rare.

Paternoite [13] ($MgB_8O_{13} \cdot 4H_2O$?) is orthorhombic (?) with a prism angle of 62°. G. = 2.11. N_m is about 1.475. Symmetrical extinction in basal rhombs. Color white. Found in salt deposits in Italy. Very rare.

Hydroboracite ($CaMgB_6O_{11} \cdot 6H_2O$) is monoclinic and fibrous parallel to c. Perfect 100 and 010 cleavages. H. = 2. G. = 2.0. F. = 2 to clear glass. Soluble in acid. Optic plane is 010; $X \wedge c = 31°$. (+) 2V = large, $\rho < v$, moderate. $N_g = 1.565$, $N_m = 1.534$, $N_p = 1.517$, $N_g - N_p = 0.048$ (Larsen [14]). Color white. Found in salt lake deposits. Rare.

Inyoite ($Ca_2B_6O_{11} \cdot 13H_2O$) is monoclinic with $a : b : c = 0.941 : 1 : 0.667$, $\beta : 62° 37'$ (Schaller [15]); $0.883 : 1 : 0.695$, $\beta = 66°$ (Poitevin–Ellsworth [16]). Crystals 001 tablets with good 001 cleavage. H. = 2. G. = 1.88. Decrepitates and fuses with much intumescence. Soluble in acid. Optic plane is 010; $X \wedge c = +37°$. (−) 2E = 118°, 2V = 70° (Schaller); 80° 33′ (Poitevin [16]), $\rho < v$, weak. $N_g = 1.520$, $N_m = 1.51$, $N_p = 1.495$, $N_g - N_p = 0.025$. Color white. Alters readily to meyerhofferite. Found in salt lake deposits with colemanite.

COLEMANITE MONO. $a : b : c = 0.777 : 1 : 0.542$, $\beta = 69° 43'$ $Ca_2B_6O_{11} \cdot 5H_2O$

PHYS. CHAR.—Crystals short prismatic; massive; perfect 010 and distinct 001 cleavages. H. = 4. G. = 2.42. F. = 1.5 with exfoliation. Soluble in hot HCl.

OPT. PROP.—The optic plane is normal to 010; the acute bisectrix Z makes an angle of 83° with c. (+) 2E = 95°, 2V = 55°, $\rho < v$, weak. $N_g = 1.614$, $N_m = 1.592$, $N_p = 1.586$, $N_g - N_p = 0.028$ (Mülheims [17]); $N_g = 1.610$, $N_m = 1.587$, $N_p = 1.582$, $N_g - N_p = 0.028$ (Eakle [18]). Color white.

OCCUR.—In arid regions in California. Rare.

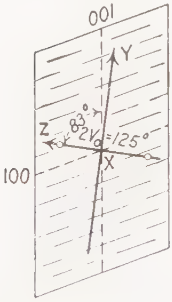

FIG. 59.—Optic orientation of colemanite.

Meyerhofferite [19] ($Ca_2B_6O_{11} \cdot 7H_2O$) is triclinic with $a : b : c = 0.792 : 1 : 0.775$. $\alpha = 89° 32'$, $\beta = 78° 19'$, $\gamma = 86° 52'$. Crystals vertical prisms or 100 tablets with perfect 010 cleavage. H. = 2. G. = 2.12. F. = easy with intumescence. Axis Z makes a moderate angle with a normal to 100. Extinction on 100 is $Z' \wedge c = 25°$; extinction on 010 is $X' \wedge c = 33°$. (−) $2V = 79°$, $\rho > v$, weak. $N_g = 1.560$, $N_m = 1.535$, $N_p = 1.500$, $N_g - N_p = 0.060$. Colorless. A dehydration product of inyoite. Rare.

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[10] *Földtani Közlöny*, XLI, 1911, p. 746 and 811.

[11] *Bull. Intern. Acad. Bohème*, XXII, 1918, p. 32.

[12] *Am. Mineral.*, X, 1925, p. 137.

[13] F. Millosevich: *Zeit. Krist.*, LX, 1924, p. 170.

[14] *U. S. Geol. Surv. Bull.* 679, 1921, p. 88.

[1] *U. S. Geol. Surv. Bull.* 610, 1916, p. 35.

[16] *Canada Geol. Surv., Bull.* 32, 1921.

[17] *Zeit. Kryst.*, XIV, 1888, p. 230. Also data for B, C, E and F.

[18] *Bull. Geol. Dept. U. Calif.*, VI, 1911, p. 179.

[19] W. T. Schaller: *U. S. Geol. Survey Bull.* 610, 1916, p. 41.

Priceite[20] ($Ca_5B_{12}O_{23} \cdot 9H_2O$?) or *pandermite* is triclinic (?), or monoclinic with $a : b : c = 0.555 : 1 : ?$, $\beta = 70° \pm$, in minute rhombic plates of 58° angle. Perfect 001, distinct 110 and indistinct 010 cleavages. H. = 3. G. = 2.4. Soluble in HCl. Axis X makes an angle of 25° with a normal to plates. Extinction on plates is about 14° from Y′ to the bisector of the acute angle (Larsen [21]). Optic plane is 010; $X \wedge c = -20°$ to $-23°$ (Linck [22]). (−) $2V = 32°$, $\rho < v$, marked. $N_g = 1.594$, $N_m = 1.591$, $N_p = 1.572$, $N_g - N_p = 0.022$. Color white. Found in borate deposits in Oregon, California and Turkey. Very rare.

4. BORATES OF DIVALENT AND MONOVALENT BASES

Ulexite ($NaCaB_5O_9 \cdot 8H_2O$) is monoclinic. Vertical fibers forming "cotton balls." H. = 1.(3.5?). G. = 1.65–1.91. F. = 1 with intumescence. Soluble in acid. Optic plane and Z normal to 010; $Y \wedge c = 23°$; also $Y \wedge c$ = small, nearly 0°; (+) 2V = moderate to large. $N_g = 1.520$, $N_m = 1.504$ (1.508), $N_p = 1.491$ (1.495), $N_g - N_p = 0.029$ (0.025). Color white. Abundant in some borate deposits in California, etc.

Kaliborite (*Hintzeite*) — ($KMg_2B_{11}O_{19} \cdot 9H_2O$) is monoclinic with $a : b : c = 1.291 : 1 : 1.757$, $\beta = 57° 41'$. Crystals complex with perfect 100 and 001 cleavages. H. = 4.5. G. = 2.13. F. = 1. Soluble in acid. Optic plane is normal to 010; $Z \wedge c = +65°$. (+) $2V = 81°$. $N_g = 1.5500$, $N_m = 1.5255$, $N_p = 1.5081$, $N_g - N_p = 0.0419$. Color white. Found in salt deposits at Stassfurt. Very rare.

5. BORATES OF TRIVALENT BASES

Eremeyevite (*Jeremejevite*—$AlBO_3$) is pseudohexagonal (with $c = 0.684$) and orthorhombic with $a : b : c = 0.552 : 1 : 0.543$. Crystals prismatic with complex twinning of biaxial and uniaxial parts. H. = 6.5. G. = 3.28. F. = 7. Insoluble in acids. Uniaxial negative to biaxial negative with $2E = 52°$, $\rho > v$. Optic plane at 30° to hexagonal edges of basal section. Optic angle variable with pressure. $N_m = 1.64$, $N_g - N_p$ = moderate(?). Colorless. Found in Siberia. Very rare.

Lagonite ($FeB_3O_6 \cdot 1 \cdot 5H_2O$) is amorphous and perhaps a mixture. Soft and earthy. Isotropic with $N = 1.64 \pm$. Color ocher-yellow. Found in Tuscan lagoons. Very rare.

6. BORATES CONTAINING TRIVALENT AND DIVALENT BASES

Rhodizite $\{(K,Na,Li)_x Be_7 Al_6 B_{14} O_{39}?\}$ is pseudocubic and tetrahedral like boracite. Indistinct 111 cleavage. H. = 8. G. = 3.3-3.4. F. = 7. Insoluble in all acids. Nearly isotropic with $N_m = 1.6935$ Na. Also $N_g - N_p = 0.0017$ at least. Heat does not make crystals isotropic. Color white or yellow. Found in pegmatite. Very rare.

Ludwigite (Mg_2FeBO_5) is orthorhombic with $a : b : c = 0.988 : 1 : ?$ Crystals prismatic fibers. H. = 5. G. = 4.0. F. = 4. Soluble in HCl. Axis Z is parallel to c. (+) 2V = very small, $\rho > v$, extreme. $N_g = 1.98$, $N_m = 1.85 \pm$, $N_p = 1.84$, $N_g - N_p = 0.14$. Color dark green with X and Y bright green, Z reddish brown.[23] In *ferriferous*

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[20] Formula as given by W. F. Foshag: *Am. Mineral.*, IX, 1924, p. 11.

[21] E. S. Larsen: *U. S. Geol. Survey Bull.*, 679, 1921, p. 122.

[22] G. Linck: *Cent. Min.*, 1923, p. 193.

[23] W. T. Schaller (*Am. Jour. Sci.*, CLXXX, 1910, p. 146) gives: sea green parallel to elongation and dark brown normal thereto.

ludwigite as much as one-fourth of the magnesium may be replaced by ferrous iron; then $N_g = 2.02$, $N_m = 1.85 \pm$, $N_p = 1.85$, $N_g - N_p = 0.17$. Color blackish green with X and Y greenish, Z reddish brown, and nearly opaque in all directions. Alters to limonite. Found in crystalline limestone. Rare.

Pinakiolite (*Manganludwigite*—Mg_2MnBO_5) is orthorhombic with $a : b : c = 0.834 : 1 : 0.588$. Crystals 010 tablets; twinning common on 011; distinct 010 cleavage. H. = 6. G. = 3.88. F. = 5. Soluble in HCl. Optic plane is 001; X = *b*. (−) 2V = 32°, $\rho < v$(?). $N_g = 2.065$, $N_m = 2.05$, $N_p = 1.908$, $N_g - N_p = 0.067$. Color black; reddish brown in section with Y > X > Z. Found in granular dolomite. Very rare.

7. COMPOUNDS CONSISTING OF BORATES WITH SALTS OF ANOTHER ACID

BORACITE PSEUDOCUBIC—ORTHORHOMBIC $Mg_7Cl_2B_{16}O_{30}$

PHYS. CHAR.—Crystals cubic, tetrahedral or dodecahedral; twinning on 111, rare; a fibrous variety is known as *stassfurtite*. 111 cleavage in traces. H. = 7. G. = 2.95. F. = 2 with intumescence. Soluble in HCl.

OPT. PROP.—The isometric form is stable above 265° C., but below that it is retained by complex twinning of an orthorhombic unit, each dodecahedral face being a twinning plane in one type, each face being normal to the bisectrix and the optic plane, which is parallel to its longer diagonal. Also complex twinning on 111 and 112; Böggild [24] gives $a : b : c = 0.9994 : 1 : 1.4144$. (+)2V = 83° ±. $N_g = 1.6730$, $N_m = 1.663$ Li, 1.6670 Na, 1.675 (blue), $N_p = 1.6622$, $N_g - N_p = 0.0108$. Color white. A greenish variety contains iron and inverts at 285° C. *Stassfurtite* has parallel extinction and positive elongation.

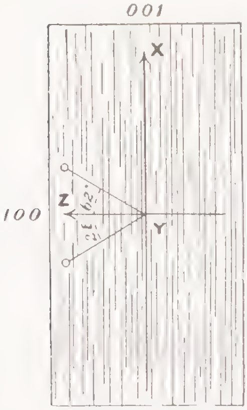
INVER.—Reversible inversion to isometric form at 265° C.

ALTER.—Becomes cloudy opaque by hydration.

OCCUR.—Found in beds of gypsum, anhydrite and salt.

DIAG.—The optic properties with the form are quite distinctive.

Nordenskioeldite ($CaSnB_2O_6$) is trigonal with $c = 0.822$. Crystals basal plates with perfect 0001 cleavage. H. = 5.5-6. G. = 4.2 (4.8?). F. = 7, but sinters. Partly soluble in HCl. Uniaxial negative with N_o estimated at 1.77 and $N_o - N_e$ = strong. Color sulphur-yellow. Found in pegmatite. Very rare.



FIR. 60.—Optic orientation of warwickite.

Warwickite $\{(Mg,Fe)_3TiB_2O_8\}$ is orthorhombic with $a : b : c = 0.977 : 1 : ?$. Crystals prismatic with perfect 100 cleavage. H. = 3-4. G. = 3.4. F. = 5.5. Decomposed by H_2SO_4. Optic plane is 010; X = *c*. (+) 2V = 59° (variable). $N_g = 1.830$, $N_m = 1.809$, $N_p = 1.806$, $N_g - N_p = 0.024$ (indices ± 0.005). Color dark brownish to dull black with X = clear yellowish brown, Y = reddish brown, Z = brown and X > Y > Z. Found in granular limestone.

Manandonite ($2Li_2O \cdot 7Al_2O_3 \cdot 2B_2O_3 \cdot 6SiO_2 \cdot 12H_2O$) is pseudohexagonal and apparently orthorhombic with perfect basal cleavage. G. = 2.89. F. = easy. Attacked by H_2SO_4. Axis Z sensibly normal to cleavage and optic plane parallel to hexagonal edges in sectors of basal sections. (+) $2E = 25°-30°$, $N_m = 1.6 \pm$, $N_g - N_p = 0.014$. Colorless. Found in pegmatite in Madagascar. Very rare.

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[24] *Zeit. Kryst.*, L, 1911, p. 428.

Howlite ($H_5Ca_2SiB_5O_{14}$) is monoclinic and tabular parallel to 100, elongated parallel to *c* (also *b*). H. = 3.5. G. = 2.58. F. = 2. Insoluble in HCl. Optic plane normal o 010; $Z \wedge c = 44° \pm$. $(-)2V$ = large. $N_g = 1.605$, $N_m = 1.598$, $N_p = 1.586$, $N_g - N_p = 0.019$, according to Larsen, while Penfield reports the optic plane normal to elongation of bladed crystals, and parallel extinction. Color white. Found with ulexite in Nova Scotia and in borax mines of California. Very rare.

Bakerite ($8CaO \cdot 5B_2O_3 \cdot 6SiO_2 \cdot 6H_2O$) is chemically related to howlite. H. = 4.5. G. = 2.7-2.9. Fuses to white bead. Gelatinizes in HCl. $N_m = 1.583$, $N_g - N_p = 0.02$. Color white, like unglazed porcelain. Found in borax mines of California. Rare.

VII. SULPHATES, ETC.

Sulphates, selenates, tellurates, chromates, molybdates, tungstates and uranates are included in this division, as well as the rare selenites and tellurites. The arrangement of salts of the normal acids begins with anhydrous normal salts of univalent bases and of maximum symmetry and ends with hydrous basic salts of several bases and of minimum symmetry. This is followed by the polythionates, polychromates, selenites and tellurites. As an appendix are added salts of two or more oxygen acids (including one acid of this division).

1. ANHYDROUS NORMAL AND ACID SULPHATES, ETC., OF MONOVALENT BASES

APHTHITALITE Trigonal $c = 1.284$ $(Na,K)_2SO_4$

Phys. Char.—Crystals basal plates, with good prismatic cleavage. H. = 3. G. = 2.7. F. = 1.5. Soluble in water.

Opt. Prop.—Uniaxial positive with $N_o = 1.487–1.491$, $N_e = 1.492–1.499$, $N_e - N_o = 0.005–0.009$ (increasing with tenor of K). With K : Na = 4 : 1, $N_o = 1.490$, $N_e = 1.496$, $N_e - N_o = 0.006$; with K : Na = 2 : 3, $N_o = 1.487$, $N_e = 1.492$, $N_e - N_o = 0.005$. With about 30 per cent $CuSO_4$ in crystal solution [1](?) the substance is orthorhombic (?) with (−) 2V = large and $N_g = 1.580$, $N_m = 1.545$, $N_p = 1.505$, $N_g - N_p = 0.075$. With K : Na : Cu = 31 : 14 : 0.5, the indices[2] are: $N_o = 1.4926$ D, $N_e = 1.5001$, $N_e - N_o = 0.0075$. White.

Inver.—The artificial salt is dimorphous.

Occur.—About volcanoes and in some salt deposits. Rare.

Thenardite (Na_2SO_4) is orthorhombic with $a : b : c = 0.598 : 1 : 1.252$; crystals pyramidal, short prismatic or basal plates. Distinct basal cleavage. H. = 2.7. G. = 2.68. F. = 1.5–2. Very soluble in water. Optic plane is 001; $Z = a$. (+) 2V = 83°, $\rho > v$, weak. $N_g = 1.485$, $N_m = 1.474$, $N_p = 1.464$, $N_g - N_p = 0.021$ (Larsen). Colorless. Changes at about 235° C. to a negative uniaxial form called *metathenardite* by Lacroix who found it at Mont Pelée; its birefringence is much less than that of thenardite. Deposited from salt lakes often with hanksite, glauberite, ulexite, etc. Also found about volcanoes.

Taylorite $\{(NH_4)_2SO_4 \cdot 5K_2SO_4\}$ is concretionary, probably orthorhombic. H. = 2. F. = 1.5(?). (+) 2V = 36°, $\rho > v$ rather strong. $N_g = 1.459$, $N_m = 1.448$, $N_p = 1.447$, $N_g - N_p = 0.012$. Colorless. Found in guano. Very rare.

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[1] H. E. Merwin: *Am. Mineral.*, VI, 1921, p. 125. Pure $CuSO_4$ has $N_m = 1.72$, $N_g - N_p = 0.02$, and is orthorhombic.

[2] F. Zambonini: *Boll. Com. Geol. Ital., Roma*, XLIX, 1920, fasc. 3.

Misenite ($HKSO_4$) is probably monoclinic in silky fibers. G. = 2.24 (Artif.). F. = easy. Soluble in water. Positive [3] with large optic angle. $Z \wedge$ elongation = 33°. $N_g = 1.487$, $N_m = 1.480$, $N_p = 1.475$, $N_g - N_p = 0.012$. Color white. In tufa near Naples; very rare.

2. HYDROUS SULPHATES, ETC., OF MONOVALENT BASES

Lecontite ($NaNH_4SO_4 \cdot 2H_2O$) is orthorhombic with $a : b : c = 0.486 : 1 : 0.633$; crystals prismatic with 110 cleavages. H. = 2.5. F. = 1. Soluble in water. Optic plane is 001; $X = a$. (−) $2E = 62° 30'$ Li, $64° 30'$ Na, $66° 30'$ Tl. $N_g = 1.453$, $N_m = 1.452$, $N_p = 1.440$, $N_g - N_p = 0.013$. Colorless. Found in guano in Central America. Very rare.

MIRABILITE (*Glauber salt*) Monoclinic $Na_2SO_4 \cdot 10H_2O$
$a : b : c = 1.116 : 1 : 1.237$, $\beta = 72° 15'$

Phys. Char.—Crystals like pyroxene in habit and angles; in crusts. Perfect 100 cleavage. H. = 1.5–2. G. = 1.46. F. = 1.5. Soluble in water. Effloresces rapidly.

Opt. Prop.—Optic plane is normal to 010; $Z \wedge c = +31°$ Li, 26.5° blue. (−) $2V = 80° 26'$, $\rho > v$ weak with strong crossed dispersion. $N_m = 1.437$, $N_g - N_p$ = very weak (Peck [4]). Sections normal to X give abnormal interference colors without extinction; other sections give sharp extinction. Color white.

Occur.—Formed from some hot springs; also in salt lakes; also by action of volcanic gases on sea water.

Diag.—Distinguished by its mode of formation, its crystal form, its efflorescent character, and its cool, bitter taste; also the low refringence, large extinction angle, and strong dispersion.

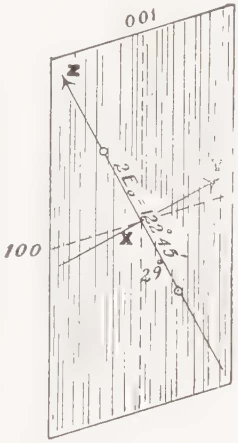

Fig. 61.—Optic orientation of mirabilite.

3. ANHYDROUS SULPHATES, ETC., OF DIVALENT BASES

SCHEELITE Tetragonal $c = 1.530$ $CaWO_4$

Comp.—Molybdenum may replace considerable tungsten.

Phys. Char.—Crystals pyramidal or thick basal tablets; symmetry tripyramidal; often massive. Twinning on 100 or 110. Distinct 111 cleavage. H. = 4.5–5. G. = 6.12 (5.94 with 8 per cent MoO_3). F. = 5. Decomposed by HCl leaving a yellow residue. Gives a deep-blue color when powder is boiled with HCl and again boiled after zinc or tin is added.

Opt. Prop.—Uniaxial positive with $N_o = 1.9185$ (red), $N_e = 1.9345$, $N_e - N_o = 0.016$. Color white, yellow, brownish, gray.

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[3] Optic data by Larsen (*U. S. Geol. Surv. Bull.* 679, 1921, p. 111) on unanalyzed sample.

[4] *Am Mineral.*, II, 1917, p. 62. Larsen gives $N_g = 1.398$, $N_m = 1.396$, $N_p = 1.394$, $N_g - N_p = 0.004$ on " recrystallized " material.

ALTER.—Alteration to wolframite is common.

OCCUR.—In veins with quartz and gold ores; in pegmatites with cassiterite, topaz, fluorite, molybdenite, wolframite; in crystalline rocks.

DIAG.—Differs from stolzite and wulfenite in sign and in much weaker birefringence.

Powellite ($CaMoO_4$) is tetragonal with $c = 1.551$; crystals pyramidal; distinct 111 cleavage. H. = 3.5. G. = 4.35 (to 4.5, with some WO_3). F. = 4. Decomposed by HCl. Uniaxial positive with $N_o = 1.967$, $N_e = 1.978$, $N_e - N_o = 0.011$ for mineral with 10 per cent WO_3. Color greenish yellow. Found in ore deposits; very rare.

Wulfenite ($PbMoO_4$) is tetragonal with $c = 1.577$; crystals basal tablets or prismatic or pyramidal. Distinct 111 cleavage. H. = 2.5-3. G. = 6.9. F. = 2. Decomposed by HCl. Uniaxial negative with $N_o = 2.402$ Li, $N_e = 2.304$, $N_o - N_e = 0.098$. Also may be distinctly biaxial. Color yellow, red, green, white. Colored crystals pleochroic with $X < Z$. Found in the oxide zone of veins with lead ores. Rare.

Stolzite ($PbWO_4$) is tetragonal with $c = 1.567$. Crystals pyramidal with imperfect 001 cleavage. H. = 3. G. = 8 ±. F. = 2. Decomposed by HNO_3. Uniaxial negative with $N_o = 2.2685$, $N_e = 2.182$, $N_o - N_e = 0.0865$. Color green, gray, brown, red. Streak colorless. In veins. Rare.

ANHYDRITE ORTHORHOMBIC $a : b : c = 0.893 : 1 : 1.001$ $CaSO_4$

PHYS. CHAR.—Crystals uncommon, varied. Twinning on 012, or lamellar on 101. Perfect 001 and 010 and distinct 100 cleavages. H. = 3. G. = 2.93. Fusible at 1450° C. after inversion at 1193° C. Soluble in HCl.

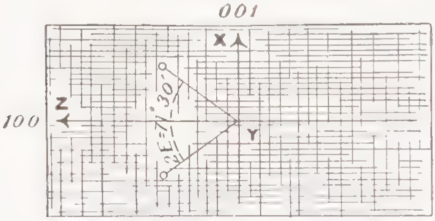

FIG. 62.—Optic orientation of anhydrite.

OPT. PROP.[5] The optic plane is 010; the positive acute bisectrix is normal to 100. Optic angle decreases slowly with heat. (+) $2V = 42°$. $\rho < v$ distinct. $N_g = 1.614$, $N_m = 1.576$, $N_p = 1.570$, $N_g - N_p = 0.044$.

Color white, grayish, bluish, red. Rare violet varieties are pleochroic in plates several millimeters thick with X and Z violet, Y colorless.

ALTER.—Anhydrite hydrates slowly to gypsum.

OCCUR.—Usually associated with gypsum and rock salt.

DIAG.—The rectangular cleavages in three directions and the strong birefringence are charactertistic.

BARITE GROUP

The barite group consists of the orthorhombic sulphates of strontium, barium and lead. The crystals are commonly tabular parallel to 001 or elongated parallel to any axis. Cleavage is distinct parallel to 001 and 110, and the optic plane [4] is parallel to 010 in all minerals of the group.

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[5] Very full data given by R. Kolb: *Zeit. Kryst.*, XLIX, 1911, p. 24.

CELESTITE ORTHORHOMBIC $a : b : c = 0.779 : 1 : 1.280$ $SrSO_4$

PHYS. CHAR.—Crystals thick basal tablets or elongated parallel to *a* or *b*. Perfect 001, nearly perfect 110 and distinct 010 cleavages; prismatic cleavage angle is 75° 50′. H. = 3.5. G. = 4.00. Fuses at 1605° C. after inversion at 1152° C. Insoluble.

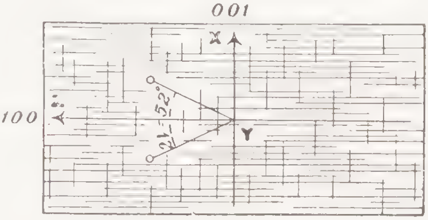

FIG. 63.—Optic orientation of celestite.

OPT. PROP.—The optic plane is 010; the positive acute bisectrix is normal to 100. (+) $2V = 51°$, $\rho < v$ distinct. $N_g = 1.631$, $N_m = 1.623$, $N_p = 1.622$, $N_g - N_p = 0.009$. Optic angle increases with heat; at 300° C. $2E = 130° 26'$ Na, at 15° C. $2E = 87° 28'$, and at $-190°$ C. $2E = 70° 20'$.

$N'_g - N_p$ on the prismatic cleavage [6] $= 0.0044$.

Color white, bluish, reddish. Bluish celestite is pleochroic in plates several millimeters thick with maximum absorption parallel to X.

OCCUR.—Usually associated with limestone or sandstone; also in veins and in beds of gypsum, halite, etc.

DIAG.—Distinguished from barite by lower relief, weaker birefringence and larger optic angle. Anhydrite has three rectangular cleavages and strong birefringence. Anglesite has very high relief and strong birefringence.

ANGLESITE ORTHORHOMBIC $a : b : c = 0.785 : 1 : 1.289$ $PbSO_4$

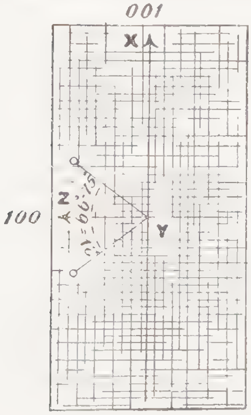

FIG. 64.—Optic orientation of anglesite.

PHYS. CHAR.—Crystals varied with distinct 001 and 110 cleavages and a prismatic cleavage angle of 76° 16′. H. = 3. G. = 6.3. Fuses at 1080° C. after inversion at 852° C. Slowly soluble in HNO_3.

OPT. PROP. The optic plane is 010; the positive acute bisectrix is normal to 100. (+) $2V = 60°$ 75°, $\rho < v$ strong. $N_g = 1.895$, $N_m = 1.883$, $N_p = 1.878$, $N_g - N_p = 0.017$. Optic angle increases with heat; at 20° C. $2E = 62° 22'$ Na, and at 200° C. $2E = 92° 40'$.

Color white, yellowish, grayish, etc. Colorless in thin section.

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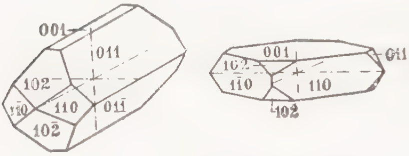
[6] H. Buttgenbach: *Minéraux et Roches*, 1916, p. 510.

Occur.—Usually associated with galena; sometimes also with cerussite in veins and ore bodies; usually formed by oxidation of galena.

Diag.—Characterized by very high relief, moderate birefringence, and large optic angle. Cerussite has extreme birefringence.

BARITE Orthorhombic $a : b : c = 0.815 : 1 : 1.314$ $BaSO_4$



Figs. 65, 66.—Crystal habits of barite.

Phys. Char.—Crystals thick basal tablets or elongated parallel to *a* with perfect 001 and 110 and imperfect 010 cleavages and a prismatic cleavage angle of 78° 22′. Twinning common on 100. H. = 3. G. = 4.5. Fuses at 1580° C. after inversion at 1149° C. Insoluble in acids.

Opt. Prop.—The optic plane is 010; the positive acute bisectrix is normal to 100. $(+)\ 2V = 37\frac{1}{2}°$, $\rho < v$ weak. $N_g = 1.648$, $N_m = 1.637$, $N_p = 1.636$, $N_g - N_p = 0.012$. Optic angle increases with heat; at 300° C. 2E = 93° 53′ Na, while at 20° C. 2E = 62° 40′.

$N'_g - N_p$ on the prismatic cleavage[7] = 0.006.

Color white, yellowish, gray, blue, red, brown. Ordinarily colorless in thin section, but deeply colored types may be pleochroic with X = ? Y = dark yellow, Z = colorless.

Barite has been found in Japan containing up to 30 per cent $PbSO_4$; it then has indices between 1.650 and 1.700. $N_g - N_p = 0.012$ to 0.014, 2E = 67° to 86°, $\rho > v$ strong. Zonal structure with more lead in yellow zones.

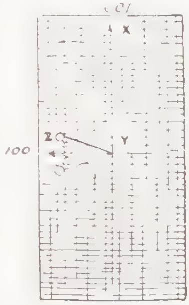


Fig. 67.—Optic orientation of barite.

Occur.—Abundant in some metalliferous veins; also found in limestones and sandstones, and in amygdules of basaltic rocks.

Diag.—Distinguished from celestite by higher relief and stronger birefringence; microchemical tests are also useful. Anhydrite has three easy rectangular cleavages and very strong birefringence. Anglesite has very high relief and moderate birefringence.

Phenicochroite ($Pb_3Cr_2O_9$) is described as orthorhombic with one perfect cleavage; usually tabular. H. = 3-3.5. G. = 5.75. F. = easy. Soluble in HCl. (+) 2V =

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[7] H. Buttgenbach: *Minéraux et Roches*, 1916, p. 510.

medium, $\rho > v$ strong. $N_g = 2.65$ Li, $N_m = 2.38$, $N_p = 2.34$, $N_g - N_p = 0.31$(?). Color cochineal to hyacinth red, altering to lemon yellow. Streak brick red. Found with crocoite in the Urals. Very rare.

CROCOITE MONO. $a : b : c = 0.960 : 1 : 0.916$, $\beta = 77° 33'$ $PbCrO_4$

PHYS. CHAR.—Crystals prismatic, etc., prism faces vertically striated. Distinct 110 cleavage at angle of 86° 19'. H. = 2.5–3. G. = 6.0. F. = 1.5.

OPT. PROP.—The optic plane is 010; $Z \wedge c = -5.5°$. (+) $2V = 57° \pm$, $\rho > v$ weak with marked inclined dispersion. $N_g = 2.66$ Li, $N_m = 2.37$, $N_p = 2.31$, $N_g - N_p = 0.35$.

Color hyacinth red. Streak orange-yellow. Luster adamantine to vitreous.

OCCUR.—In the oxide zone in quartz veins with gold, pyrite, galena, vanadinite, etc. Uncommon.

DIAG.—The color, extreme birefringence, and extinction angle are characteristic.

Raspite ($PbWO_4$) is monoclinic with $a : b : c = 1.345 : 1 : 1.114$, $\beta = 72° 23'$; crystals 100 tablets, twinned on 100. Perfect 100 cleavage. H. = 2.5. F. = 2.5–3. Decomposed by HCl. Optic plane is 010; $X \wedge c$ = large. (+) 2V = very small, $N_g = 2.30$, $N_m = 2.27$, $N_p = 2.27$, $N_g - N_p = 0.03$. Color brownish yellow with maximum absorption parallel to Z. Found with stolzite at the Broken Hill mines. Very rare.

WOLFRAMITE MONO. $a : b : c = 0.825 : 1 : 0.866$, $\beta = 89° 32'$ (Fe,Mn) WO_4

COMP.—A complete series from *ferberite* ($FeWO_4$) to *huebnerite* ($MnWO_4$).

PHYS. CHAR.—Crystals long prismatic; also 100 tablets, bladed, or lamellar; granular, massive. Perfect 010 cleavage; 100 and 102 parting. H. = 5–5.5. G. = 7.1 (ferberite) to 7.5 (*huebnerite*). F. = 2 (*ferberite*) to 4 (*huebnerite*). Decomposed by acid.

OPT. PROP.—The optic plane is normal to 010; $Z \wedge c = +17°$ to $+21°$, apparently larger in huebnerite. Optic angle large; sign + (same in ferberite?).

	Huebnerite		Wolframite		Ferberite
(+) 2V =		73°	Large		?
N_g =	2.30 D	2.32 Li	2.42 Li	2.46 Li	?
N_m =		2.22	2.32		2.40 Li
N_p =	2.20	2.17	2.26	2.31	?
$N_g - N_p$ =		0.15	0.16	0.15	?

Color brownish red to black, brown. Streak brown, gray, black. In thin section the clearest central part of crystals of huebnerite may be green; pleochroic (with exceptions) $X < Y < Z$ as follows:

	Huebnerite from Butte 0.1 mm thick	Huebnerite from France
X =	yellowish green grading into yellowish brown and blood red	golden yellow
Y =	pale green grading into brown	yellowish brown
Z =	grass green grading into dark brown and blood red	greenish yellow.

Wolframite is darker colored and ferberite is opaque except on the thinnest edges which are reddish.

OCCUR.—In veins with copper, manganese, tin ores; often associated with scheelite, fluorite, hematite, rhodochrosite.

DIAG.—Differs from sphalerite in its (extreme) birefringence and from rutile in its inclined extinction.

Lanarkite (Pb_2SO_5) is monoclinic with $a : b : c = 0.868 : 1 : 1.384$, $\beta = 88° \ 11'$; crystals 100 tablets or elongated parallel to b. Perfect 001 cleavage. H. = 2–2.5. G. = 6.4–6.8. F. = 977° C. Partly soluble in HNO_3. Optic plane is 010; acute bisectrix emerges from 001 cleavage. In 010, X makes an angle of 28° with multiple twinning lines. (−) $2V = 47°$, $\rho > v$, strong. $N_g = 2.01$, $N_m = 1.99$, $N_p = 1.93$, $N_g - N_p = 0.08$. White. Alters easily to anglesite, cerussite or leadhillite. Found in lead deposits. Very rare. Differs from anglesite and leadhillite in the optic properties of cleavage fragments.

Melanovanadite[8] $\{2CaO \cdot 3V_2O_5 \cdot 2V_2O_4(+nH_2O?)\}$ is monoclinic with $a : b : c = 0.474 : 1 : 0.582$. $\beta = 88° \ 38'$. Crystals prismatic with perfect 010 cleavage. H. = 2.5. G. = 3.48. F. = easy. Soluble in acid. Optic plane and X are probably normal to 010; extinction in 010 at 15° from c. Probably negative with 2V small. $N_p = 1.74$, $N_g - N_p$ = strong. Color black with X = dark yellowish brown and Y and Z = dark reddish brown. Found in ore deposit in Peru. Very rare.

4. HYDROUS SULPHATES, ETC., OF DIVALENT BASES

BROCHANTITE ORTHORHOMBIC $a : b : c = 0.774 : 1 : 0.487$ $4CuO \cdot SO_3 \cdot 3H_2O$

PHYS. CHAR.—Crystals prismatic, vertically striated, with perfect 010 cleavage. H. = 4. G. = 3.9. F. = 3.5. Soluble in HNO_3.

OPT. PROP.—Optic plane is 100; X = b. (−) $2V = 72°$, $\rho < v$ distinct. $N_g = 1.803$, $N_m = 1.778$, $N_p = 1.730$, $N_g - N_p = 0.073$. Color emerald green; weakly pleochroic in green with maximum absorption parallel to Z.

OCCUR.—In the oxide zones of copper veins.

DIAG.—Cleavage parallel to usual elongation which has positive sign; cleavage normal to acute bisectrix X.

Antlerite ($3CuO \cdot SO_3 \cdot 2H_2O$) is orthorhombic with[9] $a : b : c = 0.504 : 1 : 0.687$. Crystals domatic with perfect 010 cleavage. H. = 3. G. = 3.9. Optic plane is 001; X = b. (+) $2V = 35°$, $\rho > v$ very strong. $N_g = 1.785$, $N_m = 1.737$, $N_p = 1.730$, $N_g - N_p = 0.055$. Color light green with strong pleochroism; X = pale yellowish green, Y = Z = viridine green, and $Y \gg Z > X$. Found in ore deposits. Rare.

Serpierite $\{(Cu,Zn,Ca)SO_4 \cdot 3H_2O?\}$ is orthorhombic with $a : b : c = 0.859 : 1 : 1.364$. Crystals tabular with perfect 001 cleavage. G. = 2.52. Optic plane is 100; X = c. (−) $2V = 35°$, $\rho > v$ strong. $N_g = 1.647$, $N_m = 1.642$, $N_p = 1.584$, $N_g - N_p = 0.063$. Color bluish green; pleochroic with X = pale greenish, Y and Z = deep greenish blue. Found on smithsonite at Laurium, Greece. Very rare.

LANGITE ORTHORHOMBIC $a : b : c = 0.535 : 1 : 0.635$ $4CuO \cdot SO_3 \cdot 4H_2O$

PHYS. CHAR.—Crystals 001 laths elongated parallel to a; also fibrous; twinning on 110. Perfect 001 and distinct 010 cleavages. H. = 2.5–3. G. = 3.49. F. = 3.5. Soluble in HCl.

OPT. PROP.—Optic plane is 010; X = c. (−) $2V = 81°$. $N_g = 1.798$, $N_m = 1.760$, $N_p = 1.708$, $N_g - N_p = 0.090$. Color blue to greenish blue; pleochroic with X = bluish green, Y = yellowish green, Z = deep bluish green. Heating changes the color to bright green with loss of 1 H_2O, then olive green, and finally black.

OCCUR.—In slaty schists in Cornwall. Very rare.

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[8] W. Lindgren: *Proc. Nat. Acad. Sci.*, VII, 1921, p. 249; *Am. Jour. Sci.*, CCIII, 1922, p. 195.

[9] H. Ungemach: *Bull. Soc. Fr. Min.*, XLVII, 1924, p. 124.

EPSOMITE

ORTHORHOMBIC $MgSO_4 \cdot 7H_2O$

$a : b : c = 0.990 : 1 : 0.571$

PHYS. CHAR.—Crystals prismatic; commonly massive, fibrous. Perfect 010 and distinct 011 cleavages. H. = 2–2.5. G. = 1.68. F. = 1. Soluble in water with very bitter taste.

OPT. PROP.—The optic plane is 001; X = q; (–) 2V = 51° 25′, $\rho < v$ weak. $N_g = 1.461$, $N_m = 1.455$, $N_p = 1.433$, $N_g - N_p = 0.028$. Colorless.

INVER.—An artificial monoclinic form is known which is isomorphous with melanterite; the stability relations are unknown.

OCCUR.—As capillary coatings in caves and mine galleries; also in the gypsum quarries of Paris; in anthracite; in thin layers with carnallite in salt deposits, etc.

DIAG.—Distinguished by bitter taste and marked negative relief. Pickeringite gives microchemical tests of alumina and has inclined extinction.

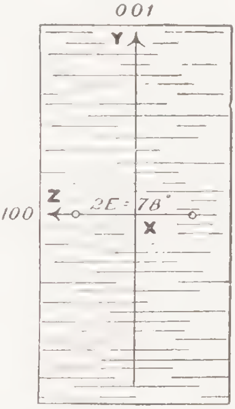

FIG. 68.—Optic orientation of epsomite.

Morenosite[9a] ($NiSO_4 \cdot 7H_2O$) is orthorhombic with $a : b : c = 0.982 : 1 : 0.566$. Crystals acicular to fibrous aggregates with perfect 010 cleavage. H. = 2–2.5. G. = 2.0. F. = 7. Soluble in water; taste astringent. Optic plane is 001; X = b. (–) 2E = 64° 22′, 2V = 41° 54′, $\rho > v$ marked. $N_g = 1.492$, $N_m = 1.489$, $N_p = 1.467$, $N_g - N_p = 0.025$. Color apple green or greenish white. An efflorescence on nickel sulphide ores. Rare.

Goslarite ($ZnSO_4 \cdot 7H_2O$) is orthorhombic with $a : b : c = 0.981 : 1 : 0.563$. Crystals acicular to hair-like in tufts with perfect 010 cleavage. H. = 2. G. = 2.0. F. = 7. Soluble in water. Dehydrates in dry air. Optic plane is 001; X = b. (–) 2V = 46° 14′, $\rho > v$ weak. $N_g = 1.481$, N_m nearly = N_g, $N_p = 1.450$, $N_g - N_p = 0.031$. Color white or stained. Formed by oxidation and hydration of sphalerite; precipitated from solution in mine galleries, etc. Rare.

Linarite ($PbO \cdot CuO \cdot SO_3 \cdot H_2O$) is monoclinic with $a : b : c = 1.716 : 1 : 0.830$, $\beta = 77° 23'$. Certain analyses indicate that linarite contains CO_2. Crystals elongated parallel to b or thick basal tablets with perfect 100 and distinct 001 cleavages. H. = 2.5. G. = 5.4. F. = 1.5. Partly soluble in HNO_3. Optic plane is normal to 010; $X \wedge c = -24°$; the acute bisectrix is nearly normal to $\bar{1}01$, a common large face. (–) 2V = 80°, $\rho < v$ marked. $N_g = 1.8593$, $N_m = 1.838$, $N_p = 1.8092$, $N_g - N_p = 0.050$. Color deep azure blue like azurite; pleochroic with X = pale blue, Y = clear blue, Z = Prussian blue. Found in oxide zone of lead-copper veins with cerussite, caledonite, etc. Rare. The optic sign is unlike that of azurite; a cleavage fragment gives an uncentered interference figure, unlike caledonite.

Herrengrundite ($3CuO \cdot 2SO_3 \cdot 6H_2O$ with Ca?) is monoclinic with $a : b : c = 1.816 : 1 : 2.80$. Crystals thin six-sided 001 plates with perfect 001 and distinct 110 cleavages. Twinning on 001. H. = 2.5. G. = 3.13. F. = 3.5. Soluble in HCl. Optic plane is normal to 010; X near *c*. (−) 2E = 66°–68°, 2V = 39°, $\rho < v$ marked. $N_g = 1.660$, $N_m = 1.649$, $N_p = 1.585$, $N_g - N_p = 0.075$. Color emerald to bluish green; pleochroic with X = very pale green, Y = Venice green, Z = turquoise green, and X < Y < Z. Found in quartz conglomerate in Hungary. Very rare.

[9a] F. Ulrich: *N. Jahrb. Min.*, I, A, 1926, p. 131.

Kieserite ($MgSO_4 \cdot H_2O$) is monoclinic with $a : b : c = 0.915 : 1 : 1.757$, $\beta = 89° 6'$. Crystals pyramidal, with perfect $11\bar{1}$ and $11\bar{3}$ and less perfect 111, 102 and 012 cleavages. H. = 3.5. G. = 2.57. F. = 2 3. Slowly soluble in water. Optic plane is 010; $Z \wedge c = +76°$, with dispersion. (+) 2V = 57°, $\rho > v$ distinct. $N_g = 1.586$, $N_m = 1.535$, $N_p = 1.523$, $N_g - N_p = 0.063$; another measure gave: $N_g = 1.5832$, $N_m = 1.5310$, $N_p = 1.5178$, $N_g - N_p = 0.0654$, 2V = 54° 46′ Na. Color white or tinted. Abundant in salt beds at Stassfurt, etc., with carnallite and gypsum. Mode of occurrence and many cleavages are distinctive.

Szmikite ($MnSO_4 \cdot H_2O$) is probably monoclinic with one perfect cleavage. H. = 1.5. G. = 3.15. F.= 7. Soluble in water. Optic plane normal to 010; Z = *b*; Y makes an angle with the elongation [10] varying notably with the wave-length. Elongation negative. $N_g = 1.62$, $N_m = ?$, $N_p = 1.57$, $N_g - N_p = 0.05$. Color white to pale rose, chalky. Alters easily. Very rare.

GYPSUM Monoclinic $CaSO_4 \cdot 2H_2O$

$a : b : c = 0.6899 : 1 : 0.4124$, $\beta = 80° 42'$

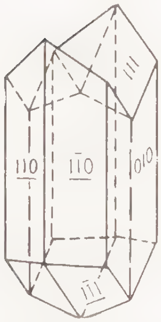

Fig. 69.—A gypsum crystal twinned on 100.

Phys. Char.—Crystals usually simple in habit, commonly tabular parallel to 010 or prismatic to acicular parallel to *c*; also massive, foliated or granular. Twinning common on 100 as arrowhead forms; also on 101. Perfect 010 and imperfect 100 and $\bar{1}11$ cleavages. H. = 2. G. = 2.32. F. = 2.5–3. Soluble in HCl.

Opt. Prop.—The optic plane is parallel with 010 at ordinary temperatures; the positive acute bisectrix makes an angle of 52° 30′ with *c* in the acute angle β. The optic angle varies rapidly with the temperature; 2E is about 95° at 20° C.; at about 91° C. it becomes 0°, and at higher temperatures the optic axes open out in a plane normal to 010; at the same time the dispersion changes from $\rho > v$ with strong inclined dispersion at 20° C. to $\rho < v$ with horizontal dispersion at 120° C.

(+) 2V = 58° 5′ Na, $N_g = 1.530$, $N_m = 1.523$, $N_p = 1.521$, $N_g - N_p = 0.009$.

Gypsum is white or stained; colorless in section.

Alter.—On heating, gypsum loses three-fourths of its water at

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[10] E. S. Larsen and M. L. Glenn: *Am. Jour. Sci.*, CC, 1920, p. 225: (+) 2V = nearly 90°. $N_g = 1.632$, $N_m = 1.595$, $N_p = 1.562$, $N_g - N_p = 0.070$ (art. cryst.).

128° C. (forming "*plaster of Paris*" which has[11] $N_o = 1.55 \pm$, $N_e = 1.57$, $N_e - N_o = 0.02$) and the remainder at 163° C.; when heated above this temperature it is "dead-burned" and not useful as plaster; such material has $N_o = 1.50$, $N_e = 1.56$, $N_e - N_o = 0.06$. In nature, gypsum may be dehydrated to anhydrite, or even reduced to sulphur.

OCCUR.—Gypsum forms occasional extensive beds in sedimentary rocks, especially with limestone. It is often associated with halite as a product of evaporation of salt lakes, estuaries, etc. It is also found about volcanoes, the gases of fumaroles reacting with lime of lavas or other rocks to produce it. It is formed by the decomposition of sulphides, such as pyrite, in the presence of lime. In igneous rocks it is a rare secondary mineral.

DIAG.—Gypsum has characteristic crystal forms, one perfect and two imperfect cleavages, is soft and hydrous, and has slight negative relief, weak birefringence, and strong inclined dispersion about the positive bisectrix of the medium optic angle.

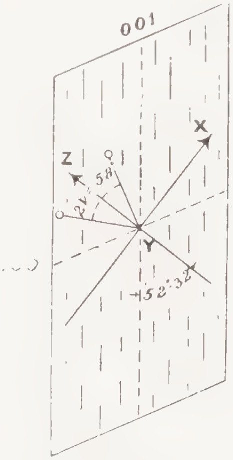

FIG. 70.—Optic orientation of gypsum.

Cuprotungstite ($CuWO_4 \cdot 2H_2O$) is cryptocrystalline, fibrous, with one distinct cleavage. H. = 4.5. F. = 3? Decomposed by HCl. N = 2.15, $N_g - N_p$ = strong. Color green. Found in copper mines associated with scheelite. Very rare.

Zinc-copper melanterite $\{(Zn,Cu)SO_4 \cdot 7H_2O\}$ is monoclinic in fibrous forms. H. = 2. G. = 2.02. F. = easy. Soluble in water. Alters easily to pentahydrate. Z = *b*. $Y \wedge$ elongation = large. (+) 2V = large, with weak dispersion.[12] $N_g = 1.488$, $N_m = 1.483$, $N_p = 1.479$, $N_g - N_p = 0.009$ (Larsen). Color blue-green. Rare.

CHALCANTHITE (*Blue vitriol*) TRICLINIC $a : b : c = 0.566 : 1 : 0.551$ $CuSO_4 \cdot 5H_2O$
$\alpha = 82°21'$ $\beta = 73°\ 11'$ $\gamma = 77°\ 37'$

PHYS. CHAR.—Crystals commonly flattened parallel to 111; with imperfect 110, $1\bar{1}0$ and 111 cleavages. H. = 2.5. G. = 2.2. F. = 3. Soluble in water from which iron precipitates copper. Taste metallic and nauseous.

OPT. PROP.—The negative acute bisectrix X lies between $-a$, $+b$, and $+c$; it makes angles of $81\frac{1}{2}°$, $43\frac{3}{4}°$, and 73° with normals to 110, $1\bar{1}0$ and 111. Z makes angles[13] of $46\frac{3}{4}°$, $12\frac{1}{2}°$, and $46\frac{1}{4}°$ with normals to the same faces. (−) 2V = 56° 2′, $\rho < v$ weak, with crossed and strong inclined dispersion. $N_g = 1.546$ 1.538, $N_m = 1.539-1.530$, $N_p = 1.516-1.511$, $N_g - N_p = 0.031-0.027$.

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[11] *Bull. Soc. Fr. Min.*, XLII, 1919, p. 298.

[12] *Am. Jour. Sci.*, CC, 1920, p. 225. Artificial *melanterite* has the optic plane parallel to 010; $Z \wedge c = -62°$; (+) 2V = 82°, $\rho > v$ weak. $N_g = 1.486$, $N_m = 1.478$, $N_p = 1.471$, $N_g - N_p = 0.015$. Color green to white.

[13] J. Mélon: *Bull. Soc. Fr. Min.*, XLVII, 1924, p. 141.

The lower indices are probably from chalcanthite containing considerable iron or zinc; there is perhaps a continuous series to *siderotilite* ($FeSO_4 \cdot 5H_2O$).

Color blue of various shades, sometimes greenish. Nearly colorless in section.

ALTER.—Varieties which are not very compact dehydrate and fall to a white powder on exposure to air.

OCCUR.—Formed by the oxidation and hydration of sulphide copper ores, such as chalcopyrite and chalcocite. It is therefore found in solution in some spring waters and some mine waters from which it forms crusts and stalactites. Rarely in fibrous form in veins.

DIAG.—Distinguished by color and taste; differs from boothite in density and optic orientation.

Iron-copper chalcanthite $\{(Fe,Cu)SO_4 \cdot 5H_2O\}$ is similar. $(-)\ 2V = 60° \pm$. $N_g = 1.543-1.534$, $N_m = 1.536$ 1.526, $N_p = 1.517-1.513$, $N_g - N_p = 0.026$ 0.021. Color pale blue or greenish blue.

Siderotilite $\{(FeSO_4 \cdot 5H_2O\}$ is triclinic with $a : b : c = 0.596 : 1 : 0.577$, $\alpha = 81° 23'$. $\beta = 69° 32'$, $\gamma = 74° 27'$. Crystals short prismatic to acicular. H. = 2-3. G. = 2.2. F. = 3. Soluble in water. $(-)\ 2V$ = moderate, $\rho > v$ weak. $N_g = 1.545$, $N_m = 1.537$, $N_p = 1.528$, $N_g - N_p = 0.017$. Color bluish green, pale green, white. A common alteration product of melanterite.

Cobalt chalcanthite ($CoSO_4 \cdot 5H_2O$) is similar. H. = 2-3. G. = 2.2. F. = 3. Soluble in water. $(-)\ 2V$ = moderate, dispersion not strong. $N_g = 1.550$, $N_m = 1.548$, $N_p = 1.530$, $N_g - N_p = 0.020$. Color rose-pink. Rare.

5. ANHYDROUS SULPHATES, ETC., OF TRIVALENT BASES .

Alumianite ($Al_2S_2O_9$) is trigonal; crystals rhombohedral, striated, resembling cubes. H. = 2-3. G. = 2.74. F. = 7. Soluble in acid. Uniaxial positive with $N_o = 1.583$, $N_e = 1.602$, $N_e - N_o = 0.019$. White. Found in mines in Spain. Very rare.

Koechlinite $\{(BiO)_2MoO_4\}$ is orthorhombic with $a : b : c = 0.977 : 1 : 1.003$. Crystals nearly square 100 tablets with diagonal striations parallel to c. Perfect 100 cleavage. Twinning on 011. Soluble in HCl. Optic plane is 001; $Z = a$. $(-)\ 2V$ = very large (perhaps $+$), $N_m = 2.55$ Li, $N_g - N_p = 0.1$ (est.). Color greenish yellow, turning brown when heated, and yellow again on cooling. Weakly pleochroic in thick plates. Found in ore deposits. Very rare.

6. HYDROUS SULPHATES, ETC., OF TRIVALENT BASES

Coquimbite $\{Fe_2(SO_4)_3 \cdot 9H_2O\}$ is trigonal with $c = 1.561$; crystals short prismatic or rhombohedral; twinning on 0001. Imperfect $10\bar{1}0$, $10\bar{1}1$ and $01\bar{1}1$ cleavages. H. = 2. G. = 2.1. F. = 4.5-5. Soluble in cold water. Uniaxial positive with $N_o = 1.5469$ Li, 1.5519 Na, $N_e = 1.5508$ Li, 1.5575 Na, $N_e - N_o = 0.0039$ Li, 0.0056 Na (Linck); the strong dispersion results in abnormal interference colors. Color white, yellow, brown, violet. Now forming in Atacama, Chile; also about volcanoes. Rare.

Ferritungstite ($Fe_2O_3 \cdot WO_3 \cdot 6H_2O$) is hexagonal, tabular to fibrous. Decomposed by acid. Uniaxial negative with $N_o = 1.80$, $N_e = 1.72$, $N_o - N_e = 0.08$ (Larsen). Fibers have positive elongation. Color pale yellow. About mines. Very rare.

Carphosiderite ($3Fe_2O_3 \cdot 4SO_3 \cdot 10H_2O$?) is trigonal (?); tenor of water questioned; may belong to alunite group. Crystals platy with distinct basal cleavage. H. = 4-4.5.

G. = 2.5–2.7. Soluble in HCl. Uniaxial negative with $N_o = 1.82$, $N_e = 1.73$, $N_o - N_e = 0.09$.[14] Also [15] $N_o = 1.81$, $N_e = 1.74$, $N_o - N_e = 0.07$. Color yellow. Found in Greenland and France. Very rare.

Rhomboclasite ($Fe_2O_3 \cdot 4SO_3 \cdot 9H_2O$) is orthorhombic; $a : b : c = 0.563 : 1 : 0.940$. Crystals platy with perfect basal cleavage. Optic plane is 100. $X = c$, (+) 2V = small. $N_g = 1.650$, $N_m = 1.551$ (Scharizer [16]); $N_g = 1.635$, $N_m = 1.550$, $N_p = 1.533$, $N_g - N_p = 0.102$ (art. cryst.—Merwin [17]). Color red with X = purple red. Y = Z = very clear yellow, colorless or pink. Loses water in stages over sulphuric acid. Deliquesces in moist air. Found in Hungary. Very rare.

Glockerite ($2Fe_2O_3 \cdot SO_3 \cdot 6H_2O$?) is in soft fibrous crusts of a brown yellow or green to black color with $N_g = 1.81$ and $N_m = 1.76$. Sign unknown. Alteration product of pyrite or marcasite. Rare.

COPIAPITE ORTHORHOMBIC $a : b : c = 0.81 : 1 : ?$ $2Fe_2O_3 \cdot 5SO_3 \cdot 18 \pm H_2O$

COMP.—Tenor of water probably variable; some types described as monoclinic, but optically most seem to be orthorhombic with a prism angle of 77°–78°. *Ihlcite, janosite, knoxvillite* and *quenstedtite* are much like copiapite, and may be identical with it, according to Larsen. But janosite is described as negative with 2V near 90°, and $N_g = 1.572$, $Nm = 1.547$, $N_p = 1.520$, $N_g - N_p = 0.052$.

PHYS. CHAR.—Crystals rhombic basal plates or fibrous parallel to *a* with perfect 001 cleavage. H. = 2.5. G. = 2.1–2.2. F. = 4.5–5. Soluble in water.

OPT. PROP.—Optic plane is 010; $X = c$,[18] (+) 2V = 45° to 74°, $\rho > v$. $N_g = 1.575–1.600$, $N_m = 1.528–1.550$, $N_p = 1.506–1.540$, $N_g - N_p = 0.057–0.070$. Variations doubtless correspond with variations in composition. Color yellow, reddish, violet; pleochroic with X = yellowish green, Y = very pale yellowish, Z = sulphur yellow. So-called sulphur in coal may be copiapite.

OCCUR.—An alteration product of iron sulphide and of melanterite. Not very rare.

"**Monoclinic copiapite**" is explained by Merwin [19] as due to unequal development of boundaries which correspond with 110, 120 and $1\bar{1}0$, 120; it seems to have the optic plane normal to 010 with $X \wedge c = +58° \pm$ (Lacroix [20]); $Z \wedge c = -53°$(Mc Caughey [21]); $Z \wedge c = 50°$ (Walker [22]); optic angle large. X = sulphur yellow, Y = colorless or greenish, Z = greenish yellow.

Ferrimolybdite (*Molybdite*—$Fe_2O_3 \cdot 3MoO_3 \cdot 7\frac{1}{2} \pm H_2O$?) is orthorhombic with $a : b : c = 0.387 : 1 : 0.475$. Crystals [22a] fibrous parallel to *c* with distinct 001 cleavage. H. = 1–2. G. = 4.5 F. = easy. Soluble in acids and decomposed by NH_4OH. Optic plane is 100; $Z = c$. (+) 2V = 28°±, $\rho < v$ marked. $N_g = 1.87–2.05$, $N_m = 1.733–1.79$, $N_p = 1.720–1.78$, $N_g - N_p = 0.12–0.26$ (Larsen). Color sulphur yellow; pleochroic with

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[14] Larsen: *U. S. Geol. Surv. Bull.* 679, 1921, p. 201; data apparently derived from the artificial substance with $9H_2O$ described by E. Posnjak and H. E. Merwin:—*Jour. Am. Chem. Soc.*, XLIV, 1922, p. 1977.

[15] Larsen classes this with jarosite, but the data are closer to those of carphosiderite

[16] *Zeit. Krist.*, LVI, 1921, p. 353.

[17] *Jour. Am. Chem. Soc.*, XLIV, 1922, p. 1965.

[18] See also "monoclinic copiapite," described below.

[19] *Jour. Am. Chem. Soc.*, XLIV, 1922, p. 1965.

[20] *Mineral. France*, IV, 1910, p. 248.

[21] *Am. Mineral.*, III, 1918, p. 162.

[22] *U. Toronto Studies, Geol. Ser.*, 14, 1922, p. 84.

[22a] E. S. Simpson: *Min. Abst.*, III, 1926, p. 131, gives the formula: $Fe_2O_3 \cdot 4MoO_2 \cdot 5H_2O + 5H_2O$.

X and Y = clear, Z = dirty gray to canary yellow; thick fibers nearly opaque parallel to Z (= elongation). Apparently an alteration product of molybdenite.

Aluminite ($Al_2O_3 \cdot SO_3 \cdot 9H_2O$) is orthorhombic (?) in earthy fibrous masses. H. = 1–2. G. = 1.66. F. = 7. Soluble in acid. X is parallel to the elongation and Z normal to a face of the zone of elongation. (+) 2V = large. $N_g = 1.470$, $N_m = 1.464$, $N_p = 1.459$, $N_g - N_p = 0.011$ (Larsen). Color white. Found in clay. Not common. By dehydration(?) the substance changes to a monoclinic form with large positive optic angle and a large extinction angle; an optic axis is nearly normal to a prism face. $N_m = 1.500$, $N_g - N_p = 0.01$ (Larsen).

Fibroferrite $\{Fe_2O_3 \cdot 2SO_3 \cdot 9(\text{or } 10)H_2O\}$ is orthorhombic (?) and fibrous parallel to *c*. H. = 2–2.5. G. = 1.86. F. = 4.5–5. Soluble in water. Z is parallel to elongation. (+) 2V = nearly 0°, $N_g = 1.575$ (1.565), $N_m = 1.534$, $N_p = 1.533$ (1.525), $N_g - N_p = 0.042$ (Larsen); $N_g = 1.568$, $N'_p = 1.530$, $N_g - N'_p = 0.038$ (Manasse[23]); $N_g = 1.561$, $N_m = N_p = 1.518$, $N_g - N_p = 0.043$ (Walker[24]). Color pale yellow with X and Y = nearly colorless, Z = pale yellow. At iron mines, etc. Rare.

Felsöbányite ($2Al_2O_3 \cdot SO_3 \cdot 10H_2O$) is orthorhombic in six-sided to lath-shaped basal scales with perfect 001 cleavage. H. = 1.5. G. = 2.33. F. = 7. Soluble in acid. Z = *c*; X parallel to elongation, (+) 2V = 48°, $\rho > v$ distinct, $N_g = 1.533$, $N_m = 1.518$, $N_p = 1.516$, $N_g - N_p = 0.017$ (Larsen). Color white. Found in Hungary. Very rare.

Paraluminite ($2Al_2O_3 \cdot SO_3 \cdot 15H_2O$) is similar, in fibrous masses. Soft. X parallel to elongation. (−) 2V = small to 0°, $N_g = 1.471$, $N_m = 1.470$, $N_p = 1.462$, $N_g - N_p = 0.009$ (Larsen). Color white, chalky. In clay beds. Very rare.

Uranospherite ($Bi_2O_3 \cdot 2UO_3 \cdot 3H_2O$) is orthorhombic (?); crystals fibrous in spherulites. Perfect 100 cleavage. H. = 2–3. G. = 6.36. Decrepitates on heating. Optic plane is 010; Z = *c*. (+) 2V = very large, $\rho < v$ strong. $N_g = 2.05$, $N_m = 1.985$, $N_p = 1.955$, $N_g - N_p = 0.095$. Color orange-yellow to brick red. Found at a mine in Saxony. Very rare.

Alunogenite $\{Al_2(SO_4)_3 \cdot 16H_2O\}$ is monoclinic; crystals 010 scales or fibrous parallel to *c*. H. = 1.5–2. G. = 1.65, F. = 7. Soluble in water. Optic plane normal to 010; $Z \wedge c = 42°$. (+) 2V = 69°. $N_g = 1.485$, $N_m = 1.478$, $N_p = 1.475$, $N_g - N_p = 0.010$; (+) 2V = small, $N_g = 1.480$, $N_m = 1.474$, $N_p = 1.473$, $N_g - N_p = 0.007$ (Larsen), $N_g = 1.47$, $N_p = 1.46$, $N_g - N_p = 0.01$ (Uhlig). Color white. Found about volcanoes and also in alum shales. Not abundant.

Montanite ($Bi_2O_3 \cdot TeO_3 \cdot 2H_2O$) is monoclinic (?); crystals fibrous; soft and earthy masses. G. = 3.79. F. = 1.5. Soluble in HCl. Fibers tend to lie on a face nearly normal to X. (−) 2V = small, $\rho < v$ extremely strong. $N = 2.09 \pm$, $N_g - N_p = 0.01 \pm$. Color yellowish white; very abnormal interference colors. Found as an alteration product of tetradymite. Very rare.

Amarantite ($Fe_2O_3 \cdot 2SO_3 \cdot 7H_2O$) is triclinic with $a : b : c = 0.769 : 1 : 0.574$, $\alpha = 95° 38'$, $\beta = 90° 24'$, $\gamma = 97° 13'$. Crystals prismatic with perfect 100 and 010 cleavages. H. = 2.5. G. = 2.2. F. = 4.5–5. Soluble in HCl. Axis X nearly normal to 100 in which $Z' \wedge c = 38°$ from right above to left below; $Z' \wedge c = -17°$ on 010. (−) 2E = 59° Li, 63° Na, 2V = 28°±, $N_g = 1.611$, $N_m = 1.605$, $N_p = 1.51$, $N_g - N_p = 0.10$. Color orange to brownish red, with X = nearly colorless, Y = pale orange yellow, Z = orange yellow. Found in ore deposits. Rare.

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[23] *Zeit. Kryst.*, LIV, 1914, p. 208.

[24] *U. Toronto Studies, Geol. Ser.*, 14, 1922, p. 87.

7. SULPHATES, ETC., OF TETRAVALENT OR HEXAVALENT BASES

Uraconite is probably a hydrous sulphate of uranium. Tiny orthorhombic 100 laths elongated parallel to *c*. Soft. Soluble in acid. The optic plane is 010; X = *a*. (+) 2V = medium, $\rho < v$ strong. $N_g = 1.85$, $N_m = 1.79$, $N_p = 1.75$, $N_g - N_p = 0.10$. Color lemon yellow. Very rare.

Zippeite ($2UO_3 \cdot SO_3 \cdot H_2O$) is probably monoclinic; crystals 010 laths with vertical elongation and distinct 010 cleavage. H. = 3. Soluble in acid. X = *b*, $Z \wedge c = 32°$ to 40° in obtuse angle β[25]. (−) 2V = large, dispersion slight. $N_g = 1.739$, $N_m = 1.689$, $N_p = 1.630$, $N_g - N_p = 0.109$; $N_g = 1.720$, $N_m = 1.680$, $N_p = 1.620$, $N_g - N_p = 0.100$; also $N_g = 1.720$, $N_m = 1.700$, $N_p = 1.630$, $N_g - N_p = 0.090$. Color orange, yellow, etc., with X = nearly colorless. Y = rather deep yellow, Z = deep yellow. Very rare.

Minasragrite ($V_2O_4 \cdot 3SO_3 \cdot 16H_2O$) is monoclinic (?); crystals fibrous or platy with perfect 010 and prismatic cleavage at 78°. F. = easy. Soluble in water. Optic plane normal to 010; $Z \wedge$ elongation = 12°; (−) 2V = large. $N_g = 1.542$, $N_m = 1.530$, $N_p = 1.518$, $N_g - N_p = 0.024$. Color blue with X = deep blue, Y = pale blue, Z = nearly colorless. An efflorescence on patronite in Peru. Very rare.

8. ANHYDROUS SULPHATES, ETC., OF DIVALENT AND MONOVALENT BASES

Langbeinite $\{K_2Mg_2(SO_4)_3\}$ is isometric; crystals tetartohedral, modified. H. = 3–4. G. = 2.83. F. = 2. Soluble in water. Absorbs water rapidly in air. Isotropic with N = 1.535. Colorless. Found in beds of halite, etc. Rare

Manganolangbeinite $\{K_2Mn_2(SO_4)_3\}$ is isometric tetrahedral[26] with G. = 3.02. Isotropic with N = 1.57. Found in a cavity in lava at Vesuvius. Very rare.

Palmierite $\{(K, Na)_2Pb(SO_4)_2\}$ is trigonal with $c = 3.761$; crystals basal laminæ, often hexagonal in outline. G. = 4.5. F. = easy. Soluble in HNO_3. Decomposed by H_2O. Uniaxial negative[27] with $N_o = 1.712$ Na, $N_o - N_e$ = strong. Colorless. Found at Vesuvius with aphthitalite. Very rare.

GLAUBERITE MONO. $a : b : c = 1.220 : 1 : 1.027$, $\beta = 67° 49'$ $Na_2Ca(SO_4)_2$

PHYS. CHAR.—Crystals basal tablets or prismatic with perfect 001 and imperfect 110 cleavages. H. = 3. G. = 2.85. F. = 1.5–2. Soluble in HCl. Partly soluble in water.

OPT. PROP.—The optic plane is normal to 010 at ordinary temperatures with $X \wedge c = +30° 46'$ Na. Therefore the basal cleavage is nearly normal to the acute bisectrix. With change of temperature the position of X, Y, and Z remain nearly constant, but the optic angle changes rapidly, as follows:

	At 5° C.	At 22° C.	At 36° C.	At 46° C.	At 58° C.	At 85° C.
Red light	2E = 16° 6′	13° 30′	11° 1′	8° 40′	0° (at 52°)	10° 47′
Yellow	2E = 14° 8′	11° 8′	8° 9′	0° (at 43°)	7° 14′	13° 14′
Green	2E = 11° 42′	8° 14′	0°	7° 8′	10° 32′	15° 15′
Blue	2E = 8° 51′	0° (at 18°)	8° 42′	11° 8′	13° 2′	17° 7′

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[25] F. Slavik (*Min. Abst.*, I, 1922, p. 290) reports parallel extinction and negative elongation with N = 1.635 parallel to *c* and 1.645 normal to *c*. Probably not zippeite.

[26] F. Zambonini and G. Carobbi: *Min. Abst.*, II, 1925, p. 382.

[27] F. Zambonini: *Comp. Rend.*, CLXXIV, 1921, p. 1419.

At 5° C. the optic plane is normal to 010 for all colors; at 85° C. it is parallel to 010 for all colors. At the same time the dispersion changes from horizontal with $\rho > v$ to inclined with $\rho < v$; the dispersion is very strong, giving abnormal interference figures in white light.

$$(-)\ 2E = 0°–17°$$

$$N_g = 1.536 \quad N_m = 1.532 \quad N_p = 1.515 \quad N_g - N_p = 0.021$$

Colorless.

Occur.—In salt deposits with halite, anhydrite, polyhalite, etc.

Diag.—Differs from anhydrite in weaker birefringence, smaller optic angle and inclined extinction; also in having only one good cleavage nearly normal to the acute bisectrix. Differs from polyhalite in much smaller optic angle; also the good cleavage is nearly normal to the acute bisectrix in glauberite, and inclined to one optic axis in polyhalite.

Vanthoffite $\{Na_6Mg(SO_4)_4\}$ is probably monoclinic; usually massive. H. = 4. G. = 2.69. F. = easy. Soluble in water. $(-)\ 2V = 84°\pm$, $\rho < v$. $N_g = 1.489$, $N_m = 1.488$, $N_p = 1.485$, $N_g - N_p = 0.004$. Colorless. In salt deposits. Rare.

9. HYDROUS SULPHATES, ETC., OF DIVALENT AND MONOVALENT BASES

Loewite $\{Na_2Mg(SO_4)_2 \cdot 2\frac{1}{2}H_2O\}$ is tetragonal with distinct 001 cleavage. H. = 3.5. G. = 2.37. F. = 1.5. Soluble in water. Uniaxial negative[28] with $N_o = 1.490$, $N_e = 1.471$, $N_o - N_e = 0.019$. Also may be slightly biaxial. Found with anhydrite in salt deposits. Rare.

SYNGENITE Mono. $a : b : c = 1.352 : 1 : 0.861$ $\beta = 75° 55'$ $K_2Ca(SO_4)_2 \cdot H_2O$

Phys. Char.—Crystals prismatic, flattened parallel to 100 with perfect 110 and 100 cleavages; twinning on 100. H. = 2.5. G. = 2.58. F. = 1.5–2. Partly soluble in water.

Opt. Prop.—Optic plane and Z normal to 010; $Y \wedge c = -2° 45'$, $(-)\ 2V = 28° 18'$ Na, $\rho < v$ strong. $N_g = 1.518$, $N_m = 1.517$, $N_p = 1.501$, $N_g - N_p = 0.017$. Color white.

On heating, becomes uniaxial for red at 127° C., for yellow at 158° C., for blue at 178° C., the optic plane changing to 010. The dispersion increases until it becomes uniaxial; then it decreases.[29]

Occur.—In beds of halite with gypsum, anhydrite, etc. Rare.

Kroehnkite $\{Na_2Cu(SO_4)_2 \cdot 2H_2O\}$ is monoclinic with $a : b : c = 0.523 : 1 : 0.435$. $\beta = 56° 17'$. Crystals prismatic to fibrous with perfect 010 and 011 cleavages. Twinning on 001. H. = 2.5. G. = 2.06. F. = 1. Soluble in water. Optic plane[30] is 010; $X \wedge c = -49°$, larger for red than blue. $(-)\ 2V = 79°$, $\rho < v$ weak. $N_g = 1.601$, $N_m = 1.578$, $N_p = 1.544$, $N_g - N_p = 0.057$. Found at a copper deposit in Chile. Rare.

Natrochalcite $(Na_2O \cdot 4CuO \cdot 3SO_3 \cdot 3H_2O)$ is monoclinic with $a : b : c = 1.423 : 1 : 1.214$, $\beta = 61° 17'$. Crystals pyramidal with perfect 001 cleavage. H. = 2.5. G. = 2.33. F. = easy. Soluble in water. Optic plane[30] is 010; $Z \wedge c = 12°$; distinctly less for blue than for red. $(+)\ 2V = 37°$, $\rho < v$ strong. $N_g = 1.714$, $N_m = 1.656$,

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[28] Görgey: *Tsch. Min. Pet. Mit.*, XXVIII, p. 334.

[29] Schreiber: *N. Jahrb. Min. Beil. Bd.*, XXXVII, p. 247.

[30] Palache and Warren: *Am. Jour. Sci.*, CLXXVI, 1908, p. 342.

$N_p = 1.649$, $N_g - N_p = 0.065$. Color emerald green. Found at a copper deposit in Chile. Very rare.

Bloedite $\{Na_2Mg(SO_4)_2 \cdot 4H_2O\}$ is monoclinic with $a : b : c = 1.349 : 1 : 0.672$, $\beta = 79° 12'$. Crystals prismatic or 001 tablets with no cleavage. H. = 3. G. = 2.23. F. = 1.5. Soluble in water. Optic plane[31] is 010; $X \wedge c = 43°$, larger for red than blue. (−) $2V = 71°$, $\rho < v$ strong. $N_g = 1.4866$, $N_m = 1.4839$, $N_p = 1.4825$, $N_g - N_p = 0.0041$ (Jaeger); $N_g = 1.489$, $N_m = 1.488$, $N_p = 1.486$, $N_g - N_p = 0.003$ (Larsen). Colorless to green or yellow. Found in salt deposits. Rare.

Leonite $\{K_2Mg(SO_4)_2 \cdot 4H_2O\}$ is monoclinic with $a : b : c = 1.386 : 1 : 1.234$, $\beta = 84° 50'$. Crystals tabular with no distinct cleavage. H. = 3. G. = 2.25. F. = easy. Soluble in water. Optic plane is 010; Z nearly normal to 001. (−) $2V = 86°$, $\rho < v$. $N_g = 1.490$, $N_m = 1.487$, $N_p = 1.483$, $N_g - N_p = 0.007$. Colorless. Found in salt deposits. Rare.

Wattevillite $\{Na_2Ca(SO_4)_2 \cdot 4H_2O\}$ is monoclinic in hair-like forms. G. = 1.81. F. = 1.5–2. Soluble in HCl. Extinction[32] of fibers not uniform; X appears parallel to fibers in some and normal in others, in some cases with a large extinction angle. (−) $2V = 48°$, $N_g = 1.459$, $N_m = 1.455$, $N_p = 1.435$, $N_g - N_p = 0.024$. Color white; luster silky. Found on lignite. Rare.

Picromerite $\{K_2Mg(SO_4)_2 \cdot 6H_2O\}$ is monoclininc with $a : b : c = 0.741 : 1 : 0.499$, $\beta = 75° 12'$; crystals short prismatic with perfect $20\bar{1}$ cleavage. H = 2.5. G. = 2.1. F. = 2. Soluble in water. Yields water at low temperature. Optic plane[33] is 010; $Z \wedge c = 103° 38'$. (+) $2V = 48°$, $\rho > v$ slight. $N_g = 1.475$, $N_m = 1.462$, $N_p = 1.460$, $N_g - N_p = 0.015$. Colorless. Found at Vesuvius and in salt deposits. Rare.

Boussingaultite $\{(NH_4)_2Mg(SO_4)_2 \cdot 6H_2O\}$ is monoclinic with $a : b : c = 0.740 : 1 : 0.492$, $\beta = 72° 54'$. Crystals short prismatic with perfect $20\bar{1}$ and distinct 010 cleavages. H. = 2. G. = 1.72. F. = 1. Soluble in water. Optic plane[33] is 010; $Z \wedge c = +95°$, (+) $2V = 51°$, $\rho > v$ slight. $N_g = 1.479$, $N_m = 1.472$, $N_p = 1.470$, $N_g - N_p = 0.009$. Color white. Found about volcanoes. Rare.

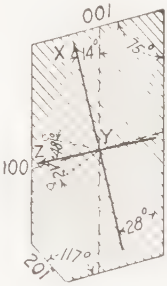

FIG. 71.—Optic orientation of picromerite.

POLYHALITE TRICLINIC $a : b : c = 0.931 : 1 : 0.856$ $K_2MgCa_2(SO_4)_4 \cdot 2H_2O$
$\alpha = 87° 31'$ $\beta = 56° 50'$ $\gamma = 88° 21'$

PHYS. CHAR.—Crystals fibrous parallel to *b* or 010 tablets. Lamellar 010 twinning; also a second which may give a grating. Distinct 100 cleavage. H. = 2.5–3. G. = 2.78. F. = 1.5. Partly soluble in water.

OPT. PROP.—The easy cleavage lamella shows multiple twinning with asymmetrical extinctions at 20° and 29°. An optic axis is nearly parallel to fibers. $2E = 95° \pm$, $N_g = 1.567$, $N_m = 1.562$, $N_p = 1.548$, $N_g - N_p = 0.019$. Color flesh red, yellow, brick red; colorless in section.

OCCUR.—Important in salt deposits of Prussia, etc.

DIAG.—In glauberite the easy cleavage is nearly normal to the acute bisectrix; in polyhalite the easy cleavage lamella shows one optic axis just outside the field of view.

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[31] *Tsch. Min. Pet. Mit.*, XXII, p. 103.

[32] Optic data by Larsen (*U. S. Geol. Surv. Bull.* 679, 1921, p. 156) on unanalyzed material.

[33] Optic data partly from art. cryst. See A. E. H. Tutton: *Trans. Chem. Soc.*, LXIX, p. 356, and LXXXVII, p. 1160; see also *Am. Mineral.*, V., 1920, p. 127.

10. HYDROUS SULPHATES, ETC., OF TRIVALENT AND MONOVALENT BASES

Potassalumite {*Potassium alum*—$KAl(SO_4)_2 \cdot 12H_2O$} is isometric; crystals octahedral or cubic, without cleavage; twinning on 111. H. = 2. G. = 1.76. F. = 1. Soluble in water. Isotropic with marked negative relief; N = 1.453–1.456 Na. Colorless. Another form known as *Kalinite* is common in nature; data on stability relations are lacking; it is probably monoclinic, fibrous; H. = 2–2.5, G. = 1.75. Z = *b*, $Y \wedge c = 13°$. (−) 2V = 52° with weak dispersion.[34] In some cases the optic angle is very small. $N_g = 1.458$, $N_m = 1.452$, $N_p = 1.430$, $N_g - N_p = 0.028$. Color white. Effloresces on clay and alum slate. Potassium alum is found about volcanoes, in caves, etc. Not rare.

Tschermigite {*Ammonium alum*—$NH_4Al(SO_4)_2 \cdot 12H_2O$} is isometric; crystals octahedral or cubic; often fibrous, no cleavage. H. = 2. G. = 1.64. F. = 1. Soluble in water. Miscible in all proportions in sodalumite. Isotropic with N = 1.457. May be weakly anisotropic. Colorless or white. A mixture of 63.5 per cent tschermigite with 37.5 per cent potassalumite has G. = 1.68 and N = 1.4586. Found in mines in Bohemia; in shale in Wyoming. Manufactured extensively at gas works.

Mendozite {$NaAl(SO_4)_2 \cdot 12H_2O$} is not isometric; crystals fibrous. H. = 3. G. = 1.73. F. = 1. Soluble in water. Uniaxial negative with $N_o = 1.459$, $N_e = 1.431$, $N_o - N_e = 0.028$. Also biaxial with (−) 2V = very small, $N_g = 1.456$, $N_m = 1.455$, $N_p = 1.434$, $N_g - N_p = 0.022$. Colorless. Found in Argentina. Artificial isometric (*sodalumite* or *sodium alum*) and monoclinic forms are known.

Alunite ($K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$) is trigonal with $c = 1.252$; crystals rhombohedral like cubes or with base with distinct basal cleavage. H = 4. G. = 2.60. F. = 7, but decrepitates. Insoluble in acid. Uniaxial positive with $N_o = 1.572$, $N_e = 1.592$, $N_e - N_o = 0.020$. Basal plates have negative elongation. Colorless or white. Produced by sulphurous vapors affecting acid volcanic rocks, etc.; also by sulphated meteoric waters affecting aluminous rocks. Differs from brucite in occurrence and association; also has inferior cleavage and brittle laminæ. Distinguished from sericite by the sign of elongation and uniaxial character.

Natroalunite ($Na_2O \cdot Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$) is similar, with distinct basal cleavage. H. = 4. G. = 2.6. Uniaxial positive with $N_o = 1.568$, $N_e - N_o = 0.01$. Rare. A mineral from Texas[35] with about 50 per cent alunite and 35 per cent natroalunite has N = 1.58, $N_g - N_p = 0.005$. A mineral from Death Valley, Calif., with 50 per cent natroalunite[35] has N = 1.585, $N_g - N_p = 0.01$.

Jarosite ($K_2O \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$) is trigonal with $c = 1.245$; crystals rhombohedral like cubes or with base; also fibrous or granular massive. Distinct basal cleavage. H. = 3. G. = 3.2. F. = 4.5. Soluble in HCl. Uniaxial negative with $N_o = 1.820$, $N_e = 1.715$, $N_o - N_e = 0.105$. Color yellow; pleochroic with X = very pale golden yellow or colorless, Z = golden yellow or straw yellow. Also biaxial, a basal section being in six segments with very small optic angle about X and the optic plane parallel to the edge. The crystal is therefore orthorhombic. $N_g = 1.820$, $N_m = 1.817$, $N_p = 1.715$, $N_g - N_p = 0.105$. Tarnishes easily and changes slowly to limonite. Found about mines, etc.; often associated with limonite. Differs from other basic iron sulphates in containing potash, and from metavoltite in its complete insolubility in water.

Natrojarosite ($Na_2O \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$) is similar with $c = 1.104$. H. = 3. G. = 3.18. F. = 4.5. Soluble in HCl. Uniaxial negative with $N_o = 1.832$, $N_e = 1.750$, $N_o - N_e = 0.082$. Color yellow or brown, pleochroic with X = colorless, Z = pale yellowish. Found in Nevada, New Mexico, South Dakota. Rare.

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[34] Optic data by Larsen (*U. S. Geol. Surv. Bull.* 679, 1921) on unanalyzed material.

[35] E. T. Wherry: *Proc. U. S. Nat. Mus.*, LI, 1916, p. 81.

Ferrinatrite $\{Na_3Fe(SO_4)_3 \cdot 3H_2O\}$ is trigonal with $c = 0.553$; crystals acicular with perfect $10\bar{1}0$ and distinct 0001 cleavages. H. = 2. G. = 2.56. F. = 1.5. Soluble in water. Uniaxial positive with $N_o = 1.559$, $N_e = 1.627$, $N_e - N_o = 0.068$. Color white or pale greenish. Found with other sulphates in Chile, etc. Very rare.

Loewigite $(K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 9H_2O)$ is very similar to alunite, but contains more water. It is cryptocrystalline, earthy. H. = 3–4. G. = 2.58. F. = 7. Partly soluble in HCl. Optic sign unknown. $N = 1.575$; $N_g - N_p = 0.01$. Found in compact lumps in coal. Rare.

Metavoltite (*Metavoltine*—$5K_2O \cdot 3Fe_2O_3 \cdot 12SO_3 \cdot 18H_2O$?) is hexagonal; crystals hexagonal scales. H. = 2.5. G. = 2.53. F. = 5. Partly soluble in water. Uniaxial negative with $N_o = 1.591$, $N_e = 1.573$, $N_o - N_e = 0.018$, also $N_o = 1.588$, $N_e = 1.578$, $N_o - N_e = 0.010$. Color yellow; pleochroic with X = pale yellow to nearly colorless, Z = deep orange yellow. Found with voltaite and pyrite in trachyte, etc. Also formed by action of fumaroles on rocks containing alumina and potassa. Differs from copiapite in form, from jarosite in solubility, and from carphosiderite in the presence of potassa.

Sideronatrite $(2Na_2O \cdot Fe_2O_3 \cdot 4SO_3 \cdot 7H_2O)$ is orthorhombic (?); crystals fibrous with perfect 100 cleavage. H. = 2–2.5. G. = 2.3. F. = 2. Soluble in acid. Optic plane is 010; $Z = c$, $(+)\ 2V = 58°$, $\rho > v$, strong. $N_g = 1.586$ $(- 1.595)$, $N_m = 1.525$, $N_p = 1.508$, $N_g - N_p = 0.078$. Color orange to straw yellow. Pleochroic with X = colorless, Y = very pale amber yellow, Z = pale amber yellow. Found in iron deposits in Chile. Very rare.

Tamarugite $\{NaAl(SO_4)_2 \cdot 6H_2O\}$ is monoclinic (?); crystals 100 laths or fibrous parallel to c. H. = 1. Multiple twinning. G. = 2.3. F. = 7. Insoluble in acid. Optic plane [34] normal to 010 with Z near or $= b$; $Y \wedge c = 30° \pm$. $(+)\ 2V = 60°$, $N_g = 1.496$, $N_m = 1.487$, $N_p = 1.484$, $N_g - N_p = 0.012$. Colorless. Found in Chile. Very rare.

11. HYDROUS SULPHATES, ETC. OF TRIVALENT AND DIVALENT BASES

Voltaite $\{5(Mg,Fe)O \cdot 2Fe_2O_3 \cdot 10SO_3 \cdot 15H_2O?\}$ is isometric and isotropic with $N = 1.602$ according to Larsen; it is tetragonal with c nearly = 1, and uniaxial in fourling twins according to Blaas. Habit octahedral. H. = 3–4. G. = 2.79. Partly soluble in water, entirely in acid. Color oil-green, brown to black. Found about volcanoes. Very rare.

Ettringite $(6CaO \cdot Al_2O_3 \cdot 3SO_3 \cdot 33H_2O?)$ is hexagonal with $c = 0.943$; crystals acicular with perfect prismatic cleavage. H. = 2–2.5. G. = 1.79. Soluble in HCl. Uniaxial negative with $N_o = 1.49$, $N_o - N_e = 0.01$ (Larsen); $N_o = 1.4661$ Na, $N_e = 1.4612$, $N_o - N_e = 0.0049$ (Brauns [36]). Color white. Found in cavities in limestone in lava. Very rare.

Zincaluminite $(6ZnO \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 18H_2O)$ is hexagonal, platy. H. = 2.5–3. G. = 2.26. F. = 7. Soluble in HNO_3. Uniaxial negative with $N_o = 1.534$, $N_e = 1.514$, $N_o - N_e = 0.020$. Color white. Found at Laurium, Greece. Very rare.

Beaverite $\{CuO.PbO \cdot (Fe,Al)_2O_3 \cdot 2SO_3 \cdot 4H_2O\}$ is hexagonal; crystals basal plates; G. = 4.36. Soluble in HCl. Uniaxial negative with $N_o = 1.83–1.87$, $N_o - N_e = 0.04 \pm$. Color brown to yellow. A secondary mineral in ore deposits. Rare.

Plumbojarosite $(PbO \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O)$ is trigonal with $c = 1.216$; crystals six sided basal plates; powdery. Rhombohedral cleavage. G. = 3.67. Uniaxial negative with $N_o = 1.872–1.878$, $N_e = 1.783–1.786$, $N_o - N_e = 0.089–0.102$. Color brown to

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[36] *N. Jahrb. Min.*, 1924, II, p. 29.

golden yellow with X = pale golden yellow, Z = dark brownish red. Also biaxial with $(-)$ $2V$ = small; X normal to plates which are divided into six segments, N_g nearly = $N_m = 1.875$, $N_p = 1.786$, $N_g - N_p = 0.089$. Found in New Mexico. Very rare.

Vegasite $(PbO \cdot 3Fe_2O_3 \cdot 3SO_3 \cdot 6H_2O)$ is very similar, but is uniaxial positive with $N_o = 1.755$, $N_e = 1.82$, $N_e - N_o = 0.065$. Color yellow; pleochroic, brownish to dull yellow. Found in ore deposits. Very rare.

Cyanotrichite (*Lettsomite*—$4CuO \cdot Al_2O_3 \cdot SO_3 \cdot 8H_2O$) is orthorhombic; crystals lath-shaped in velvety druses. G. = 2.74 ±. F. = 3. Soluble in acid. Z = elongation = c; X = a (normal to laths). $(+)$ $2V = 83°$, $\rho < v$ strong. $N_g = 1.655$, $N_m = 1.617$, $N_p = 1.588$, $N_g - N_p = 0.067$. Color bright blue with X = nearly colorless, Y = pale blue, Z = bright blue (Larsen [36a]); X = pale blue, Y = nearly colorless, Z = dark azure blue (Lacroix). Found at copper mines in Utah, etc. Very rare.

Botryogenite (*Botryogen*—$2MgO \cdot Fe_2O_3 \cdot 4SO_3 \cdot 15H_2O$) is monoclinic with $a : b : c = 1.225 : 1 : 0.826$, $\beta = 80° \ 25'$. Crystals prismatic, in uniform groups, with perfect 010 and imperfect 110 cleavages. H. = 2–2.5. G. = 2.1. F. = 4.5–5. Partly soluble in water, entirely in HCl. Optic plane normal to 010; $Z \wedge c = -12°$. $(+)$ $2V = 41°$, $\rho < v$. $N_g = 1.572$, $N_m = 1.548$, $N_p = 1.544$, $N_g - N_p = 0.028$. Color red to yellow with X = bright yellow, Y = pale red, Z = deep orange-red. Found at mines with pyrite, etc. Very rare.

Quetenite $(MgO \cdot Fe_2O_3 \cdot 3SO_3 \cdot 13H_2O)$ is monoclinic with distinct prismatic cleavage. H. = 3. G. = 2.12. F. = 4.5–5. Partly soluble in water, entirely in acid. $(+)$ $2V = 34°$, $\rho > v$ distinct. $N_g = 1.582$, $N_m = 1.535$, $N_p = 1.530$, $N_g - N_p = 0.054$. Color pale reddish brown with X and Y = colorless, Z = orange yellow to brown. Found in Chile with chalcanthite. Very rare.

Pickeringite $\{MgAl_2(SO_4)_4 \cdot 22 \pm H_2O\}$ is monoclinic; crystals acicular to fibrous. H. = 1. G. = 1.85. F. = easy. Soluble in water; astringent taste. Optic plane is 010; $Z \wedge c = 37°$ (28°—Ford [37]). $(-)$ $2V$ = medium. $N_g = 1.483$, $N_m = 1.480$, $N_p = 1.476$, $N_g - N_p = 0.007$ ($N_m = 1.485 \pm$ Ford [37]). Colorless or stained yellow to red. Produced by the action of sulphuric acid solutions on rocks. Rare.

Halotrichite $\{FeAl_2(SO_4)_4 \cdot 22 \pm H_2O\}$ is monoclinic; fibrous and silky. H. = 2. G. = 1.9 ±. F. = 4.5–5. Soluble in water; astringent taste. $Z \wedge c = 25°$ to $38°$. Colorless. $N_m = 1.49$, $N_g - N_p = 0.005$. Color white, grayish or yellowish. Produced by the action of sulphuric acid solutions on rocks. Rare.

Bilinite $(Fe''Fe'''_2(SO_4)_4 \cdot 22 \pm H_2O)$ is similar. H. = 2. G. = 1.87. Extinction angle on fibers = 35° to 39°. $N_m = 1.500$, $N_g - N_p$ = weak. Color white to yellow. Very rare.

Apjohnite $\{MnAl_2(SO_4)_4 \cdot 22 \pm H_2O\}$ is similar, in fibers with 010 and 100 well developed. H. = 1.5. G. = 1.8 ±. F. = 7. Soluble in water. Optic plane [34] is 010; $Z \wedge c = 29°$. $(-)$ $2V$ = small. $N_g = 1.482$, $N_m = 1.482$, $N_p = 1.478$, $N_g - N_p = 0.004$. Color white. Found in South Africa, Tennessee, etc. Very rare.

Dietrichite $\{(Zn,Fe,Mn)Al_2(SO_4)_4 \cdot 22 \pm H_2O\}$ is similar. H. = 2. F. = 7. Soluble in water. X = b [34]; $Z \wedge c = 29° \pm$. $(+)$ $2V$ = large, $N_g = 1.488$, $N_m = 1.480$, $N_p = 1.475$, $N_g - N_p = 0.013$. Colorless. Found in a mine in Hungary. Very rare.

Chalcoalumite.[38] $(CuO \cdot Al_2O_3 \cdot SO_3 \cdot 9H_2O)$ is probably triclinic, in thin crusts with several perfect cleavages yielding lath-shaped forms (in powder) terminated by a face at 60° to the length. Twinning plane parallel to the length of laths and nearly normal to the flat face. H. = 2.5. G. = 2.29. F. = 5. Soluble in HCl. Z makes large angles with normals to the flat face and the edge face of the laths, whose long faces have

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[36a] *Am. Mineral.*, XI, 1926, p. 213.

[37] *Am. Jour. Sci.*, CCXI, 1926, p. 301.

[38] E. S. Larsen and H. E. Vassar: *Am. Mineral*, X, 1925, p. 79.

negative elongation, though matted fibers may give apparent positive elongation. Strong dispersion giving abnormal blue interference colors. (+) $2V$ = large, $\rho > v$ strong. $N_g = 1.532$, $N_m = 1.525$, $N_p = 1.523$, $N_g - N_p = 0.009$. Color blue-green. Found on copper ores of Bisbee, Arizona. Rare.

Roemerite ($FeO\cdot Fe_2O_3\cdot 4SO_3\cdot 14H_2O$) is triclinic with $a : b : c = 1.299 : 1 : 0.830$, $\alpha = 94° 44'$, $\beta = 99° 16'$, $\gamma = 87° 22'$; crystals basal plates, apparently monoclinic; granular. H. = 3–3.5. G. = 2.15 ±. F. = 4.5–5. Soluble in water. In 101 the optic plane bisects the obtuse angle between the traces of 100 and 010; X or $Z \wedge c = 33°$. (−) $2V = 51°$, $\rho > v$ very strong with very strong crossed dispersion—sections normal to Y and Z give sharp extinction, but sections normal to X give no extinction and very abnormal interference colors. $N_g = 1.583$, $N_m = 1.571$, $N_p = 1.524$, $N_g - N_p = 0.059$. Color brown with $Y > X = Z$ in brown tints. Found in ore deposits. Among soluble sulphates, roemerite resembles only quetenite, and the latter is monoclinic.

12. SULPHATES CONTAINING URANIUM (OR URANATE-SULPHATES?)

Uranochalcite (UO_3,SO_3,CaO,CuO,H_2O) is fibrous. H. = 2–2.5. Soluble in acid; $Z = c$ (parallel to fibers). (+) $2V$ = small; $N_g = 1.662$, $N_m = 1.655$, $N_p = 1.655$, $N_g - N_p = 0.007$. Abnormal interference colors. Color green with X and Y = very pale yellowish green, Z = pale greenish yellow. Very rare.

URANOPILITE Triclinic? $CaO\cdot 8UO_3\cdot 2SO_3\cdot 25H_2O$?

Phys. Char.—Crystals tiny lath-shaped; masses earthy. G. = 3.9. Soluble in acid.

Opt. Prop.—If the flat face of the lath is taken as 010, extinction (Y′) on it is at 15° from the elongation, while X is somewhat inclined to a normal to 010. (+) $2V$ = large (Na) with $\rho < v$ extreme. Plates lying on 010 give sharp extinction in white light; others give very abnormal interference colors. $N_g = 1.631$, $N_m = 1.623$, $N_p = 1.621$, $N_g - N_p = 0.010$. Color lemon yellow.

Occur.—In Bohemia. Very rare.

Johannite [39] ($CuO\cdot UO_3\cdot SO_3\cdot 4H_2O$?) is triclinic with $a : b : c = 1.218 : 1 : 0.674$, $\alpha = 69° 24'$, $\beta = 124° 56'$, $\gamma = 132° 56'$. Crystals 010 tablets elongated parallel to c with 001 and 011 cleavages and two sets of lamellar twinning. H. = 2. G. = 3.3. F. = 3. Soluble in water. X is near b and $Y \wedge c = 5°–8°$ with marked dispersion. (+) $2V$ = very large, $\rho < v$ strong, or (−) $2V$ = very large, $\rho > v$ strong. $N_g = 1.611–1.616$, $N_m = 1.592–1.597$, $N_p = 1.572–1.577$, $N_g - N_p = 0.036–0.042$. Color yellow to black with $X < Y < Z$. Found with copper ore and pitchblende.

13. SULPHITES, SELENITES AND TELLURITES

Durdenite $\{Fe_2(TeO_3)_3\cdot 4H_2O\}$ is orthorhombic; crystals prismatic to pyramidal with perfect 001 (and 110?) faces or cleavages, the prismatic angle being 72°. H = 2–2.6. Soluble in HCl. Optic plane is 010; $X = c$. (−) $2V = 22°–24°$, $\rho > v$ strong. $N_g = 1.965$, $N_m = 1.955$, $N_p = 1.702$, $N_g - N_p = 0.263$; also $N_g = 1.95$, $N_m = 1.94$, $N_p = 1.71$, $N_g - N_p = 0.24$. Color greenish yellow with X = nearly colorless, Y = pale yellowish with a greenish tinge. Z = rather pale sulphur-yellow and $Z > Y > X$. Found in metalliferous veins; very rare.

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[39] E. S. Larsen and H. Berman: *Am. Mineral.*, XI, 1926, p. 1.

Emmonsite (hydrated ferric tellurite) is monoclinic in fibers or plates with perfect 010 and imperfect (100 and 001?) cleavages. H. = 5. Soluble in HCl. Optic plane is 010; X nearly normal (82°) to poorer imperfect cleavage and at 13° to other. (−) 2V = 20°, $\rho > v$ strong. $N_g = 2.10$, $N_m = 2.09 \pm$, $N_p = 1.95$, $N_g - N_p = 0.15$. Color yellow-green; colorless in section. Found in Arizona. Very rare.

Chalcomenite ($CuSeO_3 \cdot 2H_2O$) is monoclinic with $a : b : c = 0.722 : 1 : 0.246$, $\beta = 89° 9'$. Crystals small prismatic with base. H. = 2.5–3. G. = 3.76. F. = 1.5. Soluble in acid. Optic plane is 010 and (−) 2V = 34° in red light, 2V = 0° in green; optic plane is normal to 010 and 2V = 10° in blue light. $N_g = 1.732$, $N_m = 1.731$, $N_p = 1.710$, $N_g - N_p = 0.022$. Color blue; pale greenish blue, not pleochroic in section. Found in copper ores in Argentina. Very rare.

14. COMPOUNDS OF SULPHATES, ETC., WITH SALTS OF OTHER ACIDS

Sulphohalite ($2Na_2SO_4 \cdot NaCl \cdot NaF$) is isometric; crystals dodecahedral with no cleavage. H. = 3.5. G. = 2.43–2.49. F. = 1. Soluble in water. Isotropic [34] with N = 1.454. Colorless. Found at Borax Lake, Calif. Very rare.

Tychite ($Na_2SO_4 \cdot 2Na_2CO_3 \cdot 2MgCO_3$) is isometric; crystals octahedral. G. = 2.46 (natural), 2.59 (artificial). H. = 3.5. F. = 1. Soluble in acid. Isotropic with N = 1.508. Colorless. Found at Borax Lake, Calif., with northupite. Very rare.

Connellite $\{Cu_{19}(OH)_{32}Cl_4SO_4 \cdot 3H_2O?\}$ is hexagonal with $c = 1.185$. Crystals acicular. H. = 3. G. = 3.38. F. = 2. Soluble in HCl. Uniaxial positive with $N_o = 1.724$, $N_e = 1.746$, $N_e - N_o = 0.022$ (Merwin [40]); $N_o = 1.735$, $N_e = 1.758$, $N_e - N_o = 0.023$ (Pelloux [41]); $N_o = 1.730$, $N_e = 1.754$, $N_e - N_o = 0.024$ (Ford [42]). Color blue or greenish blue with very weak pleochroism. Found in copper deposits. Rare.

Hanksite ($9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$) is hexagonal with $c = 1.014$; crystals prismatic to basal tablets; also pyramidal. Distinct basal cleavage. H. = 3. G. 2.56. F. = 1.5. Soluble in water. Uniaxial negative with $N_o = 1.4807$, $N_e = 1.4614$, $N_o - N_e = 0.0193$. Colorless. Found at Borax Lake, Calif., etc. Rare.

Thaumasite ($CaSO_4 \cdot CaCO_3 \cdot CaSiO_3 \cdot 14H_2O$) is hexagonal with $c = 0.93$ (0.948). Crystals acicular to fibrous. H. = 3.5. G. = 1.87. F. = 7. Attacked by acid. Uniaxial negative with $N_o = 1.507$, $N_e = 1.468$, $N_o - N_e = 0.039$ (Lacroix). $N_o = 1.500$, $N_e = 1.464$, $N_o - N_e = 0.036$ (Schaller). $N_o = 1.505$, $N_e = 1.468$, $N_o - N_e = 0.037$ (Wherry). Colorless. A secondary mineral in cavities in trap, etc. Rare.

Bellite (PbO, Cr_2O_3, As_2O_5, etc.) is hexagonal in velvety coatings; acicular. H. = 2.5. G. = 5.5. F. = easy. Uniaxial negative with $N_o = 2.16$, $N_e = 2.14$, $N_o - N_e = 0.02$. Color crimson, yellow, orange, weakly pleochroic with $X < Z$. Found in ore deposits. Very rare.

Trudellite[42a] $\{Al_2(SO_4)_3 \cdot 4AlCl_3 \cdot 4Al(OH)_3 \cdot 30H_2O?\}$ is trigonal with poor rhombohedral cleavage. H = 2.5. G. = 1.93. Very deliquescent. Uniaxial negative with $N_o = 1.560$, $N_e = 1.495$, $N_o - N_e = 0.065$. Color yellow. Found in Chile. Very rare.

Beudantite ($2PbO \cdot 3Fe_2O_3 \cdot As_2O_5 \cdot 2SO_3 \cdot 6H_2O$) is trigonal with $c = 1.184$; crystals rhombohedral with distinct basal cleavage. H. = 4. G. = 4.1 ±. F. = 3.5. Soluble in HCl. Uniaxial negative with $N_o = 1.96$, $N_o - N_e$ = moderate or weak. Also biaxial with (−) 2V = medium, with abnormal dispersion, $X = c$; basal section shows six biaxial segments with lamellar twinning parallel to the edges. Color olive, yellow, brown to black; nearly colorless in section. Abnormal green interference colors. Changes to a brown mineral of higher relief which is strongly pleochroic with X′ = dark brown and Z′ = nearly colorless. Found with limonite in iron deposits. Rare.

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[40] *Am. Jour. Sci.*, CLXXVIII, 1909, p. 537.

[41] *Zeit. Kryst.*, LV, 1920, p. 313.

[42] *Am. Jour. Sci.*, CLXXXIX, 1915, p. 670.

[42a] S. G. Gordon; *Proc. Phila. Acad. Sci.*, LXXVII, 1925, p. 317.

Corkite ($2PbO \cdot 3Fe_2O_3 \cdot P_2O_5 \cdot 2SO_3 \cdot 6H_2O$) is trigonal with distinct basal cleavage. H. = 4. G. = 4.2 ±. Soluble in HCl. Uniaxial negative with $N_o = 1.93$, $N_o - N_e$ = weak. Also biaxial with $X = c$; basal section shows six biaxial segments. Color olive-green, yellow to black. Abnormal green interference colors. Occurs with limonite. Very rare.

Hinsdalite ($2PbO \cdot 3Al_2O_3 \cdot P_2O_5 \cdot 2SO_3 \cdot 6H_2O$) is trigonal (?) with $c = 1.268$. Perfect basal cleavage. H. = 4.5. G. = 4.65. F. = 7. Insoluble in HCl. Uniaxial positive with $N_o = 1.670$, $N_e = 1.689$, $N_e - N_o = 0.019$. Usually biaxial with $Z = c$ and (+) 2V = 0°–30°; basal section shows isotropic center, six biaxial segments with optic plane normal to edge in each. $N_g = 1.689$, $N_m = 1.671$, $N_p = 1.670$, $N_g - N_p = 0.019$. Color white, gray. Found in Hinsdale Co., Colo. Very rare.

Svanbergite ($2SrO \cdot 3Al_2O_3 \cdot P_2O_5 \cdot 2SO_3 \cdot 6H_2O$) is trigonal with $c = 1.206$. Perfect basal cleavage. H. = 5. G. = 3.52. F. = 6. Difficultly soluble in HCl. Uniaxial positive with $N_o = 1.64$, $N_e - N_o = 0.01$. Also biaxial with $Z = c$; basal section shows six biaxial segments. Color yellow to brown or pink. Colorless in section. Found in mines in Sweden. Very rare.

Spangolite $\{6Cu(OH)_2 \cdot AlClSO_4 \cdot 3H_2O\}$ is ditrigonal with $c = 2.011$. Crystals basal tablets to short prismatic, horizontally striated. Perfect basal cleavage. H. = 2–3. G. = 3.14. F. = 3. Soluble in dilute acids. Uniaxial negative with $N_o = 1.694$ (green), $N_e = 1.641$, $N_o - N_e = 0.053$. Color dark green with X = bluish green and Z = green. Found with cuprite and azurite. Very rare.

Sulphoborite ($2MgSO_4 \cdot 4HMgBO_3 \cdot 7H_2O$) is orthorhombic with $a : b : c = 0.62 : 1 : 0.81$. Crystals prismatic, variable. Distinct 110 and 001 cleavages. H. = 4. G. = 2.4. Fusible. Soluble in water. Optic plane is 010; $X = c$. (−) 2V = 70°±. $N_g = 1.544$, $N_m = 1.540$, $N_p = 1.527$, $N_g - N_p = 0.017$. Colorless.. Found in salt mines. Rare.

Caracolite ($PbOHCl \cdot Na_2SO_4$?) is orthorhombic with $a : b : c = 0.584 : 1 : 0.422$. Crystals pseudohexagonal pyramids twinned on 110. No cleavage. H. = 4.5. F. = 1.5–2. Partly soluble in water. (−) 2V = very large, $\rho > v$ distinct, $N_g = 1.764$, $N_m = 1.754$, $N_p = 1.743$, $N_g - N_p = 0.021$. Colorless. Found in ore deposits. Very rare.

Lossenite ($4PbO \cdot 9Fe_2O_3 \cdot 6As_2O_3 \cdot 4SO_3 \cdot 33H_2O$) is orthorhombic with $a : b : c = 0.84 : 1 : 0.95$. Crystals acute pyramidal. H. = 3–4. F. = 2–2.5. Soluble in acid. Optic plane is 100; $X = b$. (+) 2V = 50°, $\rho > v$, strong. $N_g = 1.818$, $N_m = 1.788$, $N_p = 1.783$, $N_g - N_p = 0.035$. Color brownish red. Found at Laurium, Greece. Very rare.

Caledonite ($5PbO \cdot 2CuO \cdot CO_2 \cdot 3SO_3 \cdot 6H_2O$) is orthorhombic with $a : b : c = 0.919 : 1 : 1.404$. Crystals elongated parallel to a; perfect 001 and distinct 100 cleavages. H. = 2.5–3. G. = 6.4. F. = 1.5. Partly soluble in HNO_3. Optic plane[43] is 010; $X = a$. (−) 2V = 85°, $\rho < v$ slight. $N_g = 1.909$. $N_m = 1.866$, $N_p = 1.818$, $N_g - N_p = 0.091$. Color bluish green with Y < X and Z in blue tints. Found in lead deposits in Scotland, California, etc. Rare. The obtuse bisectrix is normal to the perfect cleavage in caledonite, while no centered figure is obtained from the same cleavage in linarite.

Nitroglauberite[44] ($2Na_2SO_4 \cdot 6NaNO_3 \cdot 3H_2O$) is orthorhombic in thick laths. Soluble in water. X parallel to elongation; Y normal to face of lath. (−) 2V = 61°, $\rho < v$ rather strong. $N_g = 1.543$, $N_m = 1.500$, $N_p = 1.418$, $N_g - N_p = 0.125$. Color white. From the desert of Atacama. Very rare.

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[43] W. C. Smith: *Geol. Mag.*, LVIII, 1921, p. 558.

[44] The existence of this mineral is denied by H. W. Foote: *Am. Jour. Sci.*, IX, 1925, p. 441.

Darapskite ($Na_2SO_4 \cdot NaNO_3 \cdot H_2O$) is monoclinic with $a : b : c = 1.526 : 1 : 0.751$ $\beta = 77° 5'$. Crystals 100 tablets; twinning on 100. Perfect 100 and 010 cleavages H. = 2–3. G. = 2.2. Soluble in water. Optic plane normal to 010; $Z \wedge c = 12°$ $(-)$ $2V = 27°$, $\rho > v$ rather strong. $N_g = 1.486$, $N_m = 1.481$, $N_p = 1.391$, $N_g - N_p = 0.095$. Lamellar twinning as in plagioclase. Colorless. From the desert of Atacama Very rare.

Leadhillite ($4PbO \cdot SO_3 \cdot 2CO_2 \cdot H_2O$) is monoclinic with $a : b : c = 1.752 : 1 : 2.226$, $\beta = 89° 32'$. Crystals basal tablets. Pseudohexagonal twinning on 110; also on 310 as lamellæ. Perfect basal cleavage. H. = 2.5. G. = 6.26–6.44. F. = 1.5. Effervesces in HNO_3. Optic plane normal to 010; $X \wedge c = 5\frac{1}{2}°$. $(-)$ $2V = 10°$, $\rho < v$ strong. $N_g = 2.01$, $N_m = 2.00$, $N_p = 1.87$, $N_g - N_p = 0.14$. Axial angle decreases with heat finally becoming uniaxial at 130° C. and remaining so; it has $2E = 28°$ at $-112°$ C. Colorless. Found with lead ores in Scotland, etc. Rare.

Kainite ($MgSO_4 \cdot KCl \cdot 3H_2O$) is monoclinic with $a : b : c = 1.219 : 1 : 0.586$, $\beta = 85° 5'$; crystals 001 tablets or pyramidal. Distinct 100 and 110 cleavages. Prismatic cleavage angle is 79°. H. = 3. G. = 2.13. F. = 1.5–2. Soluble in water. The optic plane is 010; $X \wedge c = -8°$. $(-)$ $2V = 85°$; $2E = 141°$, $\rho > v$ weak, inclined dispersion distinct. $N_g = 1.516$, $N_m = 1.505$, $N_p = 1.494$, $N_g - N_p = 0.022$. Colorless or stained red. Colorless in section. Found with picromerite, halite, sylvite, etc., in salt deposits. Rare.

Creedite $\{CaSO_4 \cdot 2CaF_2 \cdot 2Al(F,OH)_3 \cdot 2H_2O\}$ is monoclinic with $a : b : c = 1.62 : 1 : 1.16$, $\beta = 85° 30'$. Crystals prismatic with perfect 100 cleavage; twinning on 100. H. = 4. G. = 2.71–2.73. F. = difficult, with intumescence. Soluble in acid. Optic plane is 010. $Z \wedge c = 42°$. $(-)$ $2V = 64°$, $\rho > v$ weak, $N_g = 1.485$, $N_m = 1.478$, $N_p = 1.461$, $N_g - N_p = 0.024$. Colorless or purple. From a fluorite mine in Colorado. Very rare.

Lindackerite ($3NiO \cdot 6CuO \cdot 2As_2O_5 \cdot SO_3 \cdot 7H_2O$) is monoclinic (?). Crystals 010 tablets or fibrous; perfect 010 cleavage. H. = 2–2.5. G. = 2–2.5. Soluble in HCl. Optic plane is 010. $X \wedge$ elongation $= 26°$. $(+)$ $2V = 73°$, $\rho < v$ strong. $N_g = 1.727$, $N_m = 1.662$, $N_p = 1.629$, $N_g - N_p = 0.098$. Color apple green. Found in Bohemia. Very rare.

Vauquelinite $\{5(Pb,Cu)O \cdot 2CrO_3 \cdot P_2O_5\}$ is monoclinic with $a : b : c = 0.75 : 1 : 1.39$. $\beta = 69° 3'$; crystals fibrous or wedge-shaped with no cleavage; concretionary. Twinning on 102. H. = 2.5–3. G. = 6 ±. F. = 2(?). Soluble in H_2SO_4. X is nearly parallel to elongation of fibers. $(-)$ 2V = nearly 0°, but biaxial. N_g nearly $= N_m = 2.22$, $N_p = 2.11$, $N_g - N_p = 0.11$. In part nearly colorless; in part brown to green with X = pale green, Y = Z = pale brown and $X < Y = Z$. Found with lead ores; not common. The reactions, color and form are quite distinctive among vein minerals.

Dietzeite ($CaCrO_4 \cdot CaI_2O_6$?) is monoclinic with $a : b : c = 1.383 : 1 : 0.952$, $\beta = 73° 28'$; crystals prismatic or 100 tablets with imperfect 100 cleavage. H. = 3–4. G. = 3.7. F. = 1.5. Soluble in hot water with separation of $CaI_2O_6 \cdot 6H_2O$ on cooling. According to Osann[45] the optic plane is normal to 010, the sign is +, and $Y \wedge c = 6°$. According to Larsen[46] the optic plane is 010, the sign is −, and the 100 perfect cleavage is sensibly normal to X. $N_g = 1.857$, $N_m = 1.842$, $N_p = 1.825$, $N_g - N_p = 0.032$. $2V = 86°$, $\rho < v$, very strong with marked inclined dispersion. Color sulphur to dark golden yellow. Found in the desert of Atacama. Rare.

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[45] *Ziet. Kryst.*, XXIII, p. 588.

[46] *U. S. Geol. Surv. Bull.* 679, 1921.

Destinezite ($2Fe_2O_3 \cdot P_2O_5 \cdot 2SO_3 \cdot 2H_2O$) is triclinic (or monoclinic) in six-sided tablets. H. = 3. G. = 2.1. F. = difficult. Soluble in HCl. According to Lacroix [47] the optic plane is 010; $X \wedge a = +39°$; $Z \wedge c = 15°$; N is between 1.64 and 1.66, $N_g - N_p = 0.026$ to 0.030. According to Larsen [46] X is not quite normal to 010; $Z \wedge$ elongation = 16°; (+) 2V = small, $\rho > v$ rather strong; $N_g = 1.665$, $N_m = 1.625$, $N_p = 1.615$, $N_g - N_p = 0.050$. Color white. Found in Belgium. Very rare.

Diadochite, perhaps contains less water; it is amorphous with N = 1.618–1.70 +. Color brown or yellow opaline; colorless to yellow in section. From alum-slate and coal mines. Very rare.

Pitticite ($Fe_2O_3, SO_3, As_2O_5, H_2O$, etc.) is amorphous. Conchoidal fracture. H. = 2–3. G. = 2.2–2.5. F. = easy. Soluble in HCl. Isotropic with N = 1.635 ±. Color brown to white; opaline; reddish brown in section. Found about old mines. Rare.

[47] *Minéral. France*, IV, 1910, p. 597.

VIII. PHOSPHATES, ETC.

The phosphates, vanadates, arsenates, and antimonates are included in this division. The arrangement begins with anhydrous acid and normal salts of monovalent bases and of maximum symmetry and continues to hydrous basic salts of several bases and of minimum symmetry. Then follow phosphites, arsenites, antimonites, hypophosphates, pyrophosphates and pyroantimonates. The division ends with other salts of phosphorus, etc., and phosphates, etc., with salts of other oxygen acids.

No natural phosphates of monovalent bases have been measured optically.

1. ANHYDROUS ACID AND NORMAL PHOSPHATES, ETC., OF DIVALENT BASES

Berzelite $\{Ca_3(Mg,Mn)_3(AsO_4)_4\}$ is isometric; crystals rare; no cleavage. H. = 5. G. = 4. F. = 3. Soluble in HNO_3. Isotropic with N = 1.727. Sulphur to orange-yellow. A contact mineral in Sweden. Very rare.

Schafarzikite [1] $(n FeO \cdot P_2O_5)$ is tetragonal with $c = 0.954$. Crystals prismatic with perfect 110 and distinct 100 cleavages. H. = 3.5. G. = 4.3. Uniaxial positive with N much above 1.74; $N_o - N_e$ = weak. Color red with X = straw yellow, Z = brownish yellow. Found in antimony ore in Hungary. Very rare.

Caryinite $\{Ca_3(Mn,Mg,Pb)_3(AsO_4)_4\}$ is orthorhombic with distinct 110 and 010 cleavages, the 110 cleavage angle being 98° 30′. H. = 3–3.5. G. = 4.25. F. = 2.5. Optic plane is 100; X = c. (+) 2V = 41°, $\rho > v$ weak. $N_g = 1.805$, $N_m = 1.780$, $N_p = 1.776$, $N_g - N_p = 0.029$. Color nut brown, not pleochroic. Alters to berzelite. Found as a contact mineral in Sweden. Very rare.

Graftonite $\{(Fe,Mn,Ca)_3(PO_4)_2\}$ is monoclinic with $a : b : c = 0.886 : 1 : 0.582$, $\beta = 66°$. Crystals interlaminated with triphylite. H. = 5. G. = 3.67. F. = 2. Soluble in HCl. X = b. Dispersion of extinction position. (+) 2V = 55°±, $\rho > v$ distinct, $N_g = 1.724$, $N_m = 1.705$, $N_p = 1.700$, $N_g - N_p = 0.024$. Color salmon pink, darkening on exposure; colorless in section. Found in pegmatite. Very rare.

Dickinsonite $\{(Mn,Fe,Ca,HNa)_3P_2O_8\}$ is monoclinic with $a : b : c = 1.732 : 1 : 1.198$, $\beta = 61° 30'$. Crystals basal tablets to micaceous with perfect 001 cleavage. H. = 3.5–4. G. = 3.34. F. = 2.5–3. Soluble in acid. Optic plane normal to 010; X = b, Y near c. (+) 2V = medium, $\rho > v$ strong. $N_g = 1.671$, $N_m = 1.662$, $N_p = 1.658$, $N_g - N_p = 0.013$. Color olive-green; absorption X > Y > Z. In albitic granite at Branchville, Conn. Very rare.

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[1] L. Tokody: *Zeit. Kryst.*, LXII, 1925, p. 123.

Fillowite $\{(Mn,Fe,Ca,HNa)_3P_2O_8\}$ is monoclinic with $a:b:c = 1.730:1:1.109$, $\beta = 58° \; 31'$. Crystals pseudorhombohedral; distinct 001 cleavage. H. = 4.5. G. = 3.43. F. = 1.5. Soluble in acid. (+) 2V = small, $\rho < v$. $N_g = 1.676$, $N_m = 1.672$, $N_p = 1.672$, $N_g - N_p = 0.004$. Color yellow, reddish brown, colorless. Found in albitic granite. Very rare.

Schultenite [1a] ($HPbAsO_4$) is monoclinic with $a:b:c = 0.864:1:0.718$, $\beta = 84° \; 36'$. Crystals 010 tablets with distinct 010 cleavage. H. = 2.5. G. = 5.94. The optic plane and X are normal to 010; $Z \wedge c + 66°$. (+) 2V = 58°, $N_g = 1.977$, $N_m = 1.910$, $N_p = 1.890$ (calc.), $N_g - N_p = 0.087$. Colorless. This is the lead arsenate of commerce. Found at Tsumeb, South Africa. Very rare.

2. HYDROUS ACID PHOSPHATES, ETC., OF DIVALENT BASES

Haidingerite ($HCaAsO_4\cdot H_2O$) is orthorhombic with $a:b:c = 0.427:1:0.493$; perfect 010 and other cleavages giving 010 tablets with angles of 33° and 147°. H. = 2. G. = 2.85. F. = 2.5. Soluble in HNO_3. Optic plane is 100; $Z = c$. (+) 2V = 58°. Dispersion slight. $N_g = 1.638$, $N_m = 1.602$. $N_p = 1.590$, $N_g - N_p = 0.048$. Colorless. Found with pharmacolite in Bohemia. Very rare.

Newberyite ($HMgPO_4\cdot 3H_2O$) is orthorhombic with $a:b:c = 0.955:1:0.936$. Crystals 100 tablets with perfect 010 and imperfect 001 cleavages. H. = 3. G. = 2.1. Soluble in HNO_3. Optic plane is 010; $Z = c$. (+) 2V = 44° 47′, $\rho < v$. $N_g = 1.533$, $N_m = 1.517$, $N_p = 1.514$, $N_g - N_p = 0.019$. Color white. Found in guano.

Pharmacolite ($HCaAsO_4\cdot 2H_2O$) is monoclinic with $a:b:c = 0.623:1:0.355$, $\beta = 83° \; 13'$; crystals 010 tablets or fibrous. Perfect 010 cleavage. H. = 2. G. = 2.7. F. = 2.5, with intumescence. Soluble in acid. The optic plane is normal to 010; $X \wedge c = +70°$. (−) 2V = 79° 24′ Na, $\rho < v$ distinct. $N_g = 1.5937$ Na, $N_m = 1.5891$, $N_p = 1.5825$, $N_g - N_p = 0.0112$. Color white or stained. Found with ores of cobalt and silver, and with arsenopyrite. Rare.

Brushite ($HCaPO_4\cdot 2H_2O$) is monoclinic with $a:b:c = 0.622:1:0.342$, $\beta = 84° \; 45'$. Crystals 010 plates or fibrous with perfect 010 and 301 cleavages. H. = 2. G. = 2.21. F. = 3 with intumescence. Soluble in dilute acid. Optic plane normal to 010; according to Lacroix [2] $X \wedge a = +21°$ to $+23°$, and (−) 2V = 81° to 87°. According to Klein [3] $X \wedge a = -74° \; 30'$ or $X \wedge c = -10° \; 15'$ Na, and (+) 2V = 86°, $\rho > v$ with distinct crossed dispersion. According to Köhler [4]: $X \wedge c = -71° \; 30'$. $N_g = 1.5509$, $N_m = 1.5455$, $N_p = 1.5392$, $N_g - N_p = 0.0117$. Color pale yellow to white. Colorless in section. Alters to monetite when heated in balsam. Found in guano, upon bones, etc. Rare.

Martinite ($H_2Ca_5P_4O_{16}\cdot \frac{1}{2}H_2O$) is monoclinic (?) in rhombic plates of angles of 74° and 106°. G. = 2.89. F. = 7, but falls to powder. Soluble in dilute acid. If the plates are parallel to 100, Z makes a small angle with a and $Y = b$, bisecting obtuse angle of rhombs. (+) 2V = medium large, $N_m = 1.59$–1.606, $N_g - N_p = 0.02$. Colorless. Found in beds derived from guano. Very rare.

Hureaulite ($H_2Mn_5P_4O_{16}\cdot 4H_2O$) is monoclinic with $a:b:c = 1.919:1:0.525$, $\beta = 84° \; 1'$. Crystals short prismatic or 100 tablets with distinct 100 cleavage. H. = 5. G. = 3.18. F. = 3. Soluble in acid. Optic plane normal to 010; $Z \wedge c = +75°$. (−) 2V = 74°, $\rho < v$ very strong, with strong crossed dispersion. $N_g = 1.660$, $N_m =$

[1a] L. J. Spencer: *Mineral. Mag.*, XXI, 1926, p. 149.

[2] *Minéral. France*, IV, 1910, p. 491.

[3] *Ber. Akad. Wiss., Berlin*, 1901, p. 720.

[4] *Tsch. Min. Pet. Mit.*, XXXVII, 1926, p. 93.

1.654, $N_p = 1.647$, $N_g - N_p = 0.013$. Optic angle decreases 6.5° between 41° and 121° C. Color orange-red, rose-violet, pink, grayish. Orange-red type pleochroic with X = colorless, Y = clear yellow to pale rose, Z = reddish yellow to reddish brown. Found in pegmatite. Very rare.

Palaite ($H_2Mn_5P_4O_{16} \cdot 3H_2O$) is monoclinic. G. = 3.2. F. = easy. Soluble in acid. $(-)$ $2V$ = large, with weak dispersion. $N_g = 1.660$, $N_m = 1.656$, $N_p = 1.652$, $N_g - N_p = 0.008$. Flesh-colored. Derived from hydration of lithiophilite and alters to hureaulite. Very rare.

Wapplerite ($HCaAsO_4 \cdot 3 \cdot 5H_2O$) is monoclinic or triclinic with $a : b : c = 0.9 : 1 : 0.262$. $\alpha = 89° 46'$, $\beta = 84° 40'$, $\gamma = 89° 49'$. Crystals equant with perfect 010 cleavage. H. = 2–2.5. G. = 2.48. Z = b (or nearly so); extinction on 010 = 20°, $(+)$ $2V = 35°$, $\rho < v$ with perceptible crossed dispersion. $N_g = 1.550$, $N_m = 1.53$. $N_p = 1.525$, $N_g - N_p = 0.025$. Colorless. Found with pharmacolite. Very rare.

3. HYDROUS NORMAL PHOSPHATES, ETC., OF DIVALENT BASES

Reddingite ($Mn_3P_2O_8 \cdot 3H_2O$) is orthorhombic with $a : b : c = 0.868 : 1 : 0.949$; crystals pyramidal with distinct 010 cleavage. H. = 3–3.5. G. = 3.1. F. = 2.5–3. Soluble in acid. The optic plane is 010; Z = c. With 4.70 FeO, $(+)$ $2V = 41°$, $\rho > v$ strong, $N_g = 1.683$, $N_m = 1.656$, $N_p = 1.651$, $N_g - N_p = 0.032$. With 2.19 FeO, $N_g = 1.674$, $N_m = 1.648$, $N_p = 1.643$, $N_g - N_p = 0.031$. Color pink, violet, red-brown, with X = colorless, Y = pinkish brown, Z = pale yellow. Found in albitic granite at Redding, Conn. Very rare.

Hopeite ($Zn_3P_2O_8 \cdot 4H_2O$) is orthorhombic with $a : b : c = 0.579 : 1 : 0.476$; crystals prismatic with perfect 100, distinct 010, and imperfect 001 cleavages. H = 3.2. G. = 3. F. = 5. Soluble in acid. Optically it is clear that there are two types, commonly intergrown (both visible in 010). α-Hopeite has slightly greater density than β-hopeite. In the former X = b, Y = c, $(-)$ $2V = 36°$, $\rho < v$ weak, $N_g = 1.59 +$, $N_m = 1.591$, $N_p = 1.572$, $N_g - N_p = 0.02 +$. In the latter X = b, Y = a or c, $(-)$ $2V = 0° \pm$, dispersion weak, $N_g = 1.582–1.59$, $N_m = 1.582$, $N_p = 1.574$, $N_g - N_p = 0.008$. Both are grayish. When warmed, α-hopeite is destroyed at 105° C. while β-hopeite becomes opaque only at 139° C. Found in zinc mines. Very rare.

Trichalcite ($Cu_3As_2O_8 \cdot 5H_2O$) is orthorhombic in plates. H. = 2.5. F. = 2. Easily soluble in HCl. X normal to plates, Y parallel to their length. $(-)$ $2V$ = large. $N_g = 1.698$, $N_m = 1.686$, $N_p = 1.67$, $N_g - N_p = 0.028 \pm$. Color verdigris-green; in section pale bluish green, not pleochroic. Found in tetrahedrite. Very rare.

Phosphophyllite[4a] $\{(Zn,Fe,Mn)_3P_2O_8 \cdot 4H_2O\}$ is monoclinic with $a : b : c = 2.079 : 1 : 2.026$, $\beta = 59° 35'$. Crystals $\bar{1}02$ tablets with perfect 100 and distinct $\bar{1}02$ and 010 cleavages. H. = 3–4. G. = 3.08. Lamellar 100 twinning. The optic plane and Z are normal to 010; $Y \wedge a = 50°$. $(-)$ $2V = 50° \pm$, $N_g = 1.616$, $N_m = 1.614$, $N_p = 1.594$, $N_g - N_p = 0.022$. Colorless or pale blue or green. A rare alteration product in pegmatite.

Brandtite ($Ca_2MnAs_2O_8 \cdot 2H_2O$) is monoclinic[5] with $a : b : c = 0.872 : 1 : 0.448$, $\beta = 80° 23'$. Crystals prismatic with distinct 010 cleavage. Twinning common on 100. H. = 5–5.5. G. = 3.67. F. = 2.5–3. Soluble in HCl. Optic plane and X are normal to 010; $Y \wedge c = +6°$ to $+8°$. $(+)$ $2V = 23°$, $\rho < v$, rather strong. $N_g = 1.724$, $N_m = 1.711$, $N_p = 1.709$, $N_g - N_p = 0.015$ (Larsen); also $N_g = 1.729$, $N_p = 1.707$,

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[4a] C. Palache and H. Berman: *Am. Mineral*, XII, 1927, p. 180.

$N_g - N_p = 0.020$ (Aminoff [5]). Colorless. Found at the Harstig Mine in Sweden. Very rare.

Picropharmacolite $\{(Ca,Mg)_3As_2O_8 \cdot 6H_2O\}$ is monoclinic with perfect 010 and 100 cleavages. Foliated aggregates. Soft. G. = 2.58. Optic plane is 010; $X \wedge c = 37°$. (+) $2V = 40°$, $\rho < v$ distinct. $N_g = 1.640$, $N_m = 1.632$, $N_p = 1.631$, $N_g - N_p = 0.009$. Found on dolomite at Joplin, Mo., etc. Very rare.

Brackebuschite $\{(Pb,Mn,Fe)_3V_2O_8 \cdot H_2O?\}$ is monoclinic (?); crystals prismatic. F. = 1.5(?). (+) 2V = large, $\rho > v$ rather strong. $N_g = 2.48$ Li, $N_m = 2.36$, $N_p = 2.28$, $N_g - N_p = 0.20$. Color black with strong pleochroism: X = nearly colorless. Y = clouded reddish brown, Z = clear reddish brown. Found in ore deposits. Very rare.

VIVIANITE GROUP

The vivianite group consists of monoclinic normal phosphates and arsenates of iron, magnesium, cobalt, nickel and zinc with eight molecules of water. The following types are included:

		$a : b : c$	β
Bobierrite	$Mg_3P_2O_8 \cdot 8H_2O$	0.76 : 1 : 0.74	74°±
Hoernesite	$Mg_3As_2O_8 \cdot 8H_2O$	?	
Vivianite	$Fe_3P_2O_8 \cdot 8H_2O$	0.747 : 1 : 0.699	75° 42′
Symplesite	$Fe_3As_2O_8 \cdot 8H_2O$	0.781 : 1 : 0.681	72° 43′
Erythrite	$Co_3As_2O_8 \cdot 8H_2O$	0.750 : 1 : 0.701	74° 59′
Annabergite	$Ni_3As_2O_8 \cdot 8H_2O$	0.8 ± : 1 : 0.7 ±	74°±
Koettigite	$Zn_3As_2O_8 \cdot 8H_2O$	0.75 : 1 : 0.7 ±	76°±

Bobierrite ($Mg_3P_2O_8 \cdot 8H_2O$) is monoclinic, crystals acicular (or lamellar in *hautefeuillite*) with distinct 010 cleavage. H. = 2. G. = 2.4. Fusible. Soluble in acid. Optic plane is normal to 010; $Z \wedge c = +29°$. (+) $2V = 71°$, $\rho < v$ weak. $N_g = 1.543$, $N_m = 1.520$, $N_p = 1.510$, $N_g - N_p = 0.033$. Colorless. In *hautefeuillite* one fifth the magnesium is replaced by calcium. The optic plane is 010 and $Z \wedge a = 45°$, with strong dispersion. (+) $2V = 55°$, $\rho < v$ weak, $N_m = 1.52$, $N_g - N_p = 0.03$. Found in guano. Very rare.

Hoernesite ($Mg_3As_2O_8 \cdot 8H_2O$) is monoclinic. Crystals 010 tablets or prismatic, with 100 cleavage. H. = 1. G. = 2.6. F. = easy. Soluble in acid. Optic plane normal to 010; $Z \wedge c = +31°$ to $+33°$. (+) $2V = 60°$, $\rho < v$. $N_g = 1.596$, $N_m = 1.571$, $N_p = 1.563$, $N_g - N_p = 0.033$. Colorless. Found in coarse calcite in Hungary. Very rare.

VIVIANITE MONO. $a : b : c = 0.747 : 1 : 0.699$. $\beta = 75° 42'$ $Fe_3P_2O_8 \cdot 8H_2O$

PHYS. CHAR.—Crystals prismatic or 100 tablets with perfect 010 and distinct 100 cleavages. Crystals are markedly flexible. H. = 2. G. = 2.6. F. = 1.5. Soluble in HCl.

OPT. PROP.—The optic plane and X are normal to 010; $Z \wedge c = +28.5°$ (Ulrich [6]). (+) 2V = large. Slight horizontal dispersion, with $\rho < v$. The optic properties change rapidly with exposure to air. Fresh vivianite is colorless, but it changes gradually to green, then blue, and finally brown as the iron is oxidized. When the mineral is powdered the change is almost instantaneous to blue, due to oxidation, as shown by Watson; [7]

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[5] G. Aminoff: *Geol. För. Förh. Stockholm*, XLI, 1919, p. 161.

[6] *Min. Abst.*, II, 1923, p. 141, and III, 1926, p. 49; *Zeit. Kryst.*, LXIV, 1926, p. 143; Buttgenbach (*Ann. Soc. Geol. Belg.*, XL, 1913, p. M 3) gives $Z \wedge c = -28.5°$.

[7] *Am. Mineral.*, III, 1918, p. 159.

in a short time the powder becomes brown. The indices change at the same time, as follows:

Color	N_g	N_m	N_p	$N_g - N_p$	2V over Z	Pleoch.	Authority
Pale green, fresh	1.627	1.598	1.580	0.047	Large	None	Larsen
	1.6294	1.6024	1.5788	0.0506	83°	Distinct	Ulrich
Blue	1.6361	1.6038	1.5809	0.0552	82° (calc.)	Weak	Rosicky
Blue	1.6365	1.6042	1.5816	0.0549	81°	Strong	Ulrich
Deep blue	1.633	1.603	1.579	0.054	85° ±	Strong	Larsen
Brown	?	?	?	?	90° +	Strong	Ulrich

X = very deep blue, Y = nearly colorless, Z = very pale olive-green or brownish.

A scratch with a hard pencil point suffices to orient a plate of vivianite which is parallel to the perfect cleavage 010 (or the face 110); in fact, a mark normal to *c* does not produce a scratch, while one in any other direction produces short cracks across the scratch *nearly normal to c*. Such plates may be elongated parallel to *c* or to $\bar{1}11$.

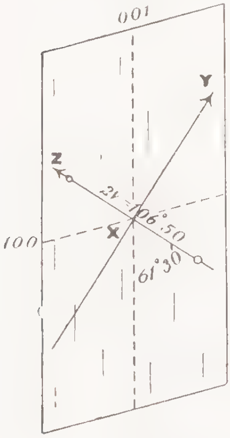

Fig. 72.—Optic orientation of vivianite.

Alter.—Changes very easily and rapidly by oxidation of iron, as noted.

Occur.—In metalliferous veins as a secondary mineral; in clay beds; with limonite; in cavities of bones.

Diag.—The deep blue color, the optic properties, and the flexibility of the crystals are characteristic.

Symplesite ($Fe_3As_2O_8 \cdot 8H_2O$) is similar: crystals prismatic or 010 tablets with perfect 010 cleavage. H. = 2.5. G. = 2.96. F. = 7. Attacked by HCl. Optic plane normal to 010; $Z \wedge c = +32°$. (−) $2V = 87°$, $\rho > v$ rather strong. $N_g = 1.702$, $N_m = 1.668$, $N_p = 1.635$, $N_g - N_p = 0.067$. Color pale indigo or green and pleochroic with X = bluish green to deep blue, Y = colorless to pale greenish yellow, Z = yellowish to yellowish green. Found with siderite or pharmacosiderite. Very rare.

Ferrisymplesite[8] ($3Fe_2O_3 \cdot 2As_2O_5 \cdot 16H_2O$) is fibrous with G. = 2.89, N = 1.65, $N_g - N_p$ = strong. Color deep amber brown, slightly pleochroic. Rare.

Erythrite ($Co_3As_2O_8 \cdot 8H_2O$) is similar: crystals prismatic, vertically striated, or 010 tablets with perfect 010 and indistinct 100 and $\bar{1}01$ cleavages. Cleavage flakes flexible normal to *c*. H. = 1.5–2.5. G. = 2.95. F. = 2. Soluble in HCl to rose-red solution. Optic plane normal to 010; $Z \wedge c = + 32°$. (±) $2V = 89° \pm$, $\rho > v$ weak, with slight crossed dispersion. $N_g = 1.6986$, $N_m = 1.6619$, $N_p = 1.6263$, $N_g - N_p = 0.0723$ Na (Gaubert). $N_g = 1.701$, $N_m = 1.663$, $N_p = 1.629$, $N_g - N_p = 0.072$ (Larsen). Color crimson to gray with X = pale pinkish, Y = very pale violet, Z = red with $Z > X > Y$; colors vary. Streak pale red; dry powder lavender blue. Formed by the oxidation of cobalt ores in the surface part of veins. The pink color and optic properties of cleavage lamellæ are characteristic. *Lavendulan*[9] is probably a cupriferous variety of erythrite; it has $N_g = 1.725$, $N_m = 1.715$, N_p = ?, and inclined extinction.

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[8] T. L. Walker and A. L. Parsons: *U. Toronto Studies, Geol. Ser.* 17, 1924, p. 16.

[9] W. F. Foshag: *Am. Mineral.*, IX, 1924, p. 29.

Annabergite ($Ni_3As_2O_8 \cdot 8H_2O$) is closely related to erythrite; crystals fibrous or 010 tablets with perfect 010 cleavage. H. = 2.5–3. G. = 3–3.1. F. = 4. Soluble in HCl. Optic plane normal to 010; $Z \wedge c = +35.5°$ in acute angle (100 : $\bar{1}01$) of cleavage rhombs. (−) 2V = 84°, $\rho > v$ rather strong, with distinct crossed dispersion. $N_g = 1.687$, $N_m = 1.658$, $N_p = 1.622$, $N_g - N_p = 0.065$. Color apple-green; colorless or weakly pleochroic in sections in green tints. Formed by oxidation of nickel ores. Rare. *Cabrerite* is a variety containing magnesium replacing some nickel; in it X is normal to 010 and $Z \wedge c$ is 33°. (−) 2V = nearly 90°. $N_g = 1.689$, $N_m = 1.654$, $N_p = 1.62$, $N_g - N_p = 0.069$. Found with brown spar in Spain and in zinc mines in Greece. Very rare.

Koettigite ($Zn_3As_2O_8 \cdot 8H_2O$) is similar; crystals vertical fibers with perfect 010 cleavage. H. = 2.5–3. G. = 3.1. F. = 3? Soluble in acid. Optic plane normal to 010; $Z \wedge c = +37°$ (small according to Larsen). (+) 2V = 77°, $\rho < v$ rather strong. Extinction imperfect on 010 on account of horizontal dispersion. $N_g = 1.717$, $N_m = 1.683$, $N_p = 1.662$, $N_g - N_p = 0.055$. Color carmine or brownish. Found with smaltite. Very rare.

Huegelite is a monoclinic hydrous vanadate of lead and zinc with $a : b : c = 0.489 : 1 : 0.384$, $\beta = 60°\ 12'$. Crystals 010 laths. G. = 5. Z = *b*, $X \wedge c$ = small (red); $Y \wedge c$ = small (blue). (+) 2V = small (red); (+) 2V = 0° (red-orange); (+)2V = large (blue). $N_m = 1.915$, $N_g - N_p$ = rather weak. Color yellow, orange, brown, with X = very pale greenish yellow, Y = pale orange. 010 plates show sharp parallel extinction in white light with abnormal green interference colors. Other sections give no extinction in white light and abnormal interference colors. Found on galena in an ore deposit. Very rare.

Roselite $\{Ca_2(Co,Mg)\,As_2O_8 \cdot 2H_2O\}$ is triclinic with $a : b : c = 0.454 : 1 : 0.656$, $\alpha = 90°\ 21'$, $\beta = 91°$, $\gamma = 89°\ 20'$. Crystals small, complex with complicated lamellar twinning and perfect 100 cleavage. H. = 3.5. G. = 3.5–3.6. F. = 3. Soluble in acid. X nearly normal to 100 cleavage; in 100, $Y \wedge$ twinning lamellæ = 3°. (+) 2V = medium, $\rho < v$ strong. $N_m = 1.725 \pm$, $N_g - N_p = 0.01$. Color rose-red with X and Y = pale rose-red, Z = nearly colorless. Zonal growths common. Found in mines in Germany. Very rare.

Fairfieldite $\{Ca(Mn,Fe)_2P_2O_8 \cdot 2H_2O\}$ is triclinic with $a : b : c = 0.28 : 1 : 0.20$, $\alpha = 102°\ 9'$, $\beta = 94°\ 33'$, $\gamma = 77°\ 20'$. Crystals equant with perfect 010 and distinct 100 cleavages. H. = 3.5. G. = 3.1. F. = 4. Soluble in acid. Extinction angle in 100 is 40° to *c*; in 010 it is 10° to *c* and an optic axis is near the edge of the field. (+) 2V = large, $\rho > v$ medium. $N_g = 1.654$, $N_m = 1.644$, $N_p = 1.636$, $N_g - N_p = 0.018$. With [10] only one per cent FeO: $N_g = 1.652$, $N_m = 1.641$, $N_p = 1.633$, $N_g - N_p = 0.019$. Colorless in section. Found in albitic granite in Connecticut. Very rare.

Anapaite ($Ca_2FeP_2O_8 \cdot 4H_2O$) is triclinic with $a : b : c = 0.707 : 1 : 0.878$, $\alpha = 97°\ 12'$, $\beta = 95°\ 17'$, $\gamma = 70°\ 11'$. Crystals vertical fibers with perfect 101 and distinct 010 cleavages. H. = 3.5. G. = 2.8. Soluble in cold acid. Extinction on 100 is 15° to *c*. Some plates are nearly normal to Z. (+) 2V = 53°, $\rho > v$. $N_g = 1.649$, $N_m = 1.613$, $N_p = 1.602$, $N_g - N_p = 0.047$. Color greenish white. Found in limonite mines in Russia. Very rare.

Messelite ($Ca_2FeP_2O_8 \cdot 2 \cdot 5H_2O$?) is perhaps a partially dehydrated anapaite. It is triclinic, tabular on 100 with one good cleavage. H. = 3–3.5. G. = 3. Extinction on 100 at 20° from *c*, an optic axis being visible. (+) 2V = medium, dispersion slight, $N_g = 1.680$, $N_m = 1.653$, $N_p = 1.644$, $N_g - N_p = 0.036$. Colorless or brownish. Found in a bituminous clay slate. Very rare.

Stewartite $\{Mn_3(PO_4)_2 \cdot 4H_2O?\}$ is triclinic in 100 tablets with distinct 010 cleavage. G. = 2.94. Axis X nearly normal to 100; extinction on 010 is 56° ($X' \wedge c$); 010 plate shows optic axis in the field. (−) 2V = very large with strong dispersion. $N_g = 1.69$, $N_m = 1.66$, $N_p = 1.63$, $N_g - N_p = 0.06$. Color yellow, with X = colorless, Y = very pale yellow, Z = yellow. An alteration product of lithiophilite. Very rare.

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[10] K. K. Landes: *Am. Mineral.*, X, 1925, p. 355.

Parahopeite ($Zn_3P_2O_8 \cdot 4H_2O$) is triclinic with $a : b : c = 0.773 : 1 : 0.712$, $\alpha = 93° 22'$, $\beta = 91° 12'$, $\gamma = 91° 22'$. Crystals 100 tablets with perfect 010 cleavage and common lamellar twinning on 100. H. = 3.5–4. G. = 3.21–3.31. F. = easy. Soluble in HCl. X is near a; extinction on 100 is $Y' \wedge c = 30°$; extinction on 010 is 0° to 25°. (+) 2V = nearly 90°, $\rho < v$. $N_g = 1.637$, $N_m = 1.625$, $N_p = 1.614$, $N_g - N_p = 0.023$. Stable to 163° C. Colorless. Found at Broken Hill mines, Rhodesia. Very rare.

4. ANHYDROUS BASIC (OR HALOGEN-CONTAINING) PHOSPHATES, ETC., OF DIVALENT BASES

APATITE GROUP

The members of the apatite group are hexagonal phosphates, arsenates or vanadates of calcium or lead with a small amount of fluorine, chlorine, or, much less commonly, hydroxyl (or even perhaps oxide, carbonate or sulphate). Apatite is the only mineral of the group found commonly in rocks, the crystal habit is short prismatic with basal or pyramidal terminations. The minerals are all negative and normally uniaxial, but the presence of arsenic seems to result in a distinctly biaxial character. The chief species and subspecies are the following:

Svabite		$3Ca_3As_2O_8 \cdot CaF_2$	or	$Ca_5FAs_3O_{12}$
Apatite	Fluorapatite..........	$3Ca_3P_2O_8 \cdot CaF_2$	or	$Ca_5FP_3O_{12}$
	Chlorapatite.........	$3Ca_3P_2O_8 \cdot CaCl_2$	or	$Ca_5ClP_3O_{12}$
	Manganapatite.......	$3(Ca,Mn)_3P_2O_8 \cdot CaF_2$	or	$(Ca,Mn)_5FP_3O_{12}$
	Strontianapatite or Fermorite..........	$3(Ca,Sr)_3P_2O_8 \cdot Ca(F,OH)_2$	or	$(Ca,Sr)_5(F,OH)P_3O_{12}$
Pyromorphite..................		$3Pb_3P_2O_8 \cdot PbCl_2$	or	$Pb_5ClP_3O_{12}$
Vanadinite.....................		$3Pb_3V_2O_8 \cdot PbCl_2$	or	$Pb_5ClV_3O_{12}$
Mimetite.......................		$3Pb_3As_2O_8 \cdot PbCl_2$	or	$Pb_5ClAs_3O_{12}$

The following formulas and names are tentatively assigned to minerals closely related to apatite, and perhaps in part derived from it:

Voelckerite or oxidapatite.....	$3Ca_3P_2O_8 \cdot CaO$
Hydroxylapatite (unknown alone)	$3Ca_3P_2O_8 \cdot Ca(OH)_2$
Podolite or carbapatite.........	$3Ca_3P_2O_8 \cdot CaCO_3$
Sulphatapatite	$3Ca_3P_2O_8 \cdot CaSO_4$

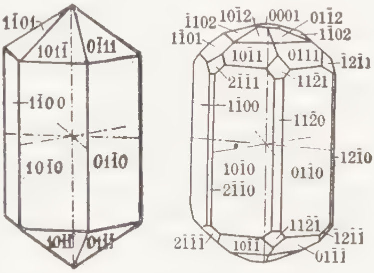
Other related minerals include dahllite, francolite (or staffelite) and collophanite.

Svabite ($Ca_5FAs_3O_{12}$) is hexagonal with $c = 0.714$. Crystals prismatic or fibrous. H. = 5. G. = 3.52. F. = 5. Soluble in acid.

Uniaxial negative with $N_o = 1.706$, $N_e = 1.698$, $N_o - N_e = 0.008$. Colorless. Found at the Harstig mine in Sweden. Very rare.

APATITE HEXAGONAL $c = 0.7346$ $Ca_5(F,Cl)P_3O_{12}$

PHYS. CHAR. Crystals long to short prismatic, terminated by the base or a pyramid with basal cleavage in traces. H. = 5. G. = 3.16 – 3.22. F. = 5. Soluble in HCl or HNO_3.



FIGS. 73, 74.—Crystal habits of apatite.

OPT. PROP.—Negative and commonly strictly uniaxial; also biaxial with the optic angle (2E) exceeding 10°. Common apatite is in most cases *fluorapatite* with very little chlorine. It has N_o ranging from 1.632 to 1.648, N_e from 1.630 to 1.643 and $N_o - N_e$ from 0.002 to 0.005. *Chlorapatite* is rare; a sample from a meteorite[11] has: $N_o = 1.655$, $N_e = 1.651$, $N_o - N_e = 0.004$. Natural apatite is supposed to have varying amounts of oxygen, hydroxyl, CO_3 and SO_4 (as well as chlorine) replacing the fluorine. The effects of such replacements on the index are quite imperfectly known, but apparently slight, since *voelckerite* or *oxidapatite* is reported to have G. = 2.99, F. = 1540° C. $N_o = 1.633$, $N_e = 1.629$, and $N_o - N_e = 0.004$, but another sample[12] gave: $N_o = 1.651$, $N_e = 1.645$, $N_o - N_e = 0.006$; *podolite* or *carbapatite* is said to have $N_o = 1.635$ and $N_o - N_e = 0.0075$. But an apatite from Steiermark with CaF_2 to surplus CaO as 4 to 3 gave Grosspietsch[13] $N_o = 1.6357$ Na, $N_e = 1.6328$, $N_o - N_e = 0.0029$. Podolite is also biaxial with six sectors in basal section and hour-glass structure in vertical section. It is found in phosphorite nodules in Russia. A *sulphatapatite* from Laacher See with $CaF_2 = 3.37$, $CaCl_2 = 0.25$, CaO (surplus) = 2.98, and $CaSO_4 = 2.92$ gave Brauns[14] $N_o = 1.6383$ Na, $N_e = 1.6350$, and $N_o - N_e = 0.0033$.

Manganese may replace up to at least 20 per cent of the calcium in *manganapatite*; its presence causes an increase in the indices of refraction; for example manganapatite from Buckfield, Maine,[10] with 8.67 per cent MnO has $N_o = 1.642$ Na, $N_e = 1.639$, $N_o - N_e =$

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[11] E. V. Shannon and E. S. Larsen: *Am. Jour. Sci.*, CCIX, 1925, p. 250.

[12] *Zeit. Kryst.*, LXII, 1925, p. 162.

[13] *Zeit. Kryst.*, LIV, 1915, p. 461.

[14] *N. Jahrb. Min. Beil. Bd.*, XLI, 1916, p. 60.

0.003. It is almost colorless. Manganapatite (G. = 3.16–3.39) is green or lavender with X = bluish green, Z = rich green and X > Z as found in India. *Strontianapatite* or *fermorite* contains SrO up to 10 per cent. G. = 3.5 ±. $N_o = 1.660$, $N_o - N_e$ = weak. Color white or pink. Found in India. Rare. An apatite[15] rich in Di has G. = 3.31, $N_o = 1.648$, $N_e = 1.645$, $N_o - N_e = 0.003$.

Color green, blue, red, white, gray, brown. Usually colorless in section, but may be gray, blue or brown with uniform or irregular distribution of color. Heating usually changes the colored types to colorless condition. Colored varieties weakly pleochroic with X > Z; but in rare cases X < Z is reported.

Incl.—Some apatite contains numerous dark inclusions; these may be arranged in vertical lines, or centrally, or zonally. Fluid or gaseous inclusions in some cases.

Alter.—Apatite is usually quite fresh even when the enclosing minerals have undergone complete alteration.

Occur.—Apatite is widely, but very sparsely distributed in all kinds of rocks. It occurs most abundantly in regions of crystalline schists, as in Renfrew County, Ontario, and in Odenwald. In Canada it is associated with metamorphosed limestones and accompanied by titanite, amphibole, zircon, pyroxene, garnet, vesuvianite. It is found in sedimentary rocks chiefly as the result of organic deposits. In igneous rocks it is somewhat more abundant in basic types; very rarely is it more than an accessory constituent. Finally, it is found in dikes and veins, sometimes in large crystals.

Diag.—Apatite in its common crystal form is readily distinguished from most other minerals by that means; also by its moderate relief, very weak birefringence and lack of distinct cleavage. Apatite differs from quartz in having higher relief, weaker birefringence and negative sign. Anhedral apatite is more easily confused with other minerals; it is distinguished from eudialite by somewhat higher refraction, absence of distinct cleavage, and chemical reactions; melilite is optically of variable sign, has distinct cleavage and abnormal interference colors; gehlenite has somewhat higher relief than apatite; vesuvianite has still higher relief.

Pyromorphite ($Pb_5ClP_3O_{12}$) is hexagonal with $c = 0.729$; crystals prismatic, horizontally striated, with prismatic and pyramidal cleavages only in traces. H. = 4. G. = 7.0 ±. F. = 1156° C. Soluble in HNO_3. Uniaxial negative with $N_o = 2.061$ Na, $N_e = 2.049$, $N_o - N_e = 0.012$. Also biaxial when arsenic is present; the optic angle is small, decreasing with decrease in tenor of arsenic. Color green, yellow, brown, gray, white; colorless or weakly pleochroic in section with X = yellow to greenish yellow, Z = green, and X < Z. Alters rarely to cerussite or even galena. Found in the oxide zone of lead deposits. Pyromorphite is exceptional in combining moderate birefringence with very high relief; it differs from apatite in its mode of occurrence and much higher relief, and from vanadinite in its much weaker birefringence; mimetite is usually biaxial distinctly.

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[15] S. G. Gordon: *Proc. Phila. Acad. Sci.*, LXXVI, 1924, p. 265.

Vanadinite ($Pb_5ClV_3O_{12}$) is hexagonal with $c = 0.712$; crystals prismatic to fibrous. H. = 3. G. = 7.0 ±. F. = 990° C. Decomposed by HCl. Uniaxial negative with $N_o = 2.354$ C, $N_e = 2.299$, $N_o - N_e = 0.055$. Color red, yellow, brown; colorless in section or pleochroic with X = lemon yellow with reddish spots, Z = brownish red to orange, and X < Z. Found in the oxide zone of lead deposits. Not common. Vanadinite has stronger birefringence than other members of the apatite group. Lacroix notes that by treating the mineral on an object glass with dilute nitric acid and evaporating to dryness the residue is dark red if the mineral is vanadinite, lighter red if endlichite, and colorless if any other member of the group.

Endlichite is a variety of vanadinite containing arsenic; it is uniaxial (or slightly biaxial) with $N_o = 2.348$ D, $N_e = 2.311$, $N_o - N_e = 0.037$; another crystal gave: $N_o = 2.25$, $N_e = 2.20$, $N_o - N_e = 0.05$. Color yellow.

Mimetite ($Pb_5ClAs_3O_{12}$) is hexagonal with $c = 0.725$ and indistinct prismatic cleavage. H. = 3.5. G. = 7.15. F. = 1140° C. Soluble in HNO_3. Uniaxial negative with $N_o = 2.135$, $N_e = 2.120$, $N_o - N_e = 0.015$ (Larsen). $N_o = 2.144$–2.149 Na, $N_e = 2.129$–2.135, $N_o - N_e = 0.014$–0.018 (Bowman).[16] Also biaxial, 2E attaining 64°; basal sections show six sectors, each having the optic plane parallel to the hexagonal face and X normal to the base. Color yellow, brown, or white; colorless in section or weakly pleochroic in yellow tints with X < Z. Found in oxide zone of lead deposits. Not common.

Hedyphane[16a] seems to be a variety of mimetite containing 5 to 15 per cent CaO. Uniaxial positive with $N_o = 1.948$, N_a, $N_e = 1.958$, $N_e - N_o = 0.010$. Color bluish. Found at Franklin, N. J.

Cornetite[17] $\{(CuOH)_3PO_4\}$ is orthorhombic with $a : b : c = 0.985 : 1 : 0759$. Crystals short domatic. H. = 5. G. = 4.1. Soluble in HCl. Optic plane is 001; $X = a$. (−) 2E = 55°. (2V = 33° Tl). $N_g = 1.8 \pm$, $N_m = 1.8 \pm$, $N_p = 1.765$, $N_g - N_p = 0.102$–0.144. Color peacock to greenish blue; not perceptibly pleochroic. Zonal growth not rare. Found in ore deposits in Africa. Very rare. Cornetite is perhaps the same as pseudomalachite, which has not been found in good crystals.

OLIVENITE ORTHORHOMBIC $a : b : c = 0.940 : 1 : 0.673$ $Cu_2(OH)AsO_4$

PHYS. CHAR.—Crystals 100 tablets elongated parallel to c, equant, or elongated parallel to a with difficult 110 and 011 cleavages. H. = 3. G. = 4.1–4.4. F. = 2–2.5. Soluble in HCl.

OPT. PROP.—Optic plane is 001; $X = a$. Crystals from Utah have (+) 2V = 82°, $\rho < v$ strong. $N_g = 1.863$, $N_m = 1.810$, $N_p = 1.772$, $N_g - N_p = 0.091$. Color green, or, rarely, yellow, white, brown; in section pale and not pleochroic or X = pale greenish, Y = yellowish to greenish, Z = pale greenish to yellow. Crystals from Cornwall have 2V = nearly 90°, probably variable in sign, $N_g = 1.829$, $N_m = 1.785$–1.795, $N_p = 1.747$, $N_g - N_p = 0.082$. Y parallel to elongation. Color olive green to dark brown; in section pale green and not pleochroic.

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[16] *Mineral. Mag.*, XIII, 1913, p. 324.

[16a] C. Palache and H. Berman: *Am. Mineral.*, XII, 1927, p. 187.

[17] A. Hutchinson and A. M. Macgregor: *Mineral. Mag.*, XIX, 1921, p. 225.

Occur.—In the oxide zone of copper deposits in crystals and also in fibrous masses known as *wood-copper*. Uncommon.

Higginsite $\{CaCu(OH)AsO_4\}$ is orthorhombic with $a : b : c = 0.794 : 1 : 0.624$. Crystals prismatic or domatic. H. = 4.5. G. = 4.33. F. = 3. Soluble in acid. Optic plane is 010; X = *a*. (−) 2V = nearly 90°, $\rho > v$ rather strong. $N_g = 1.846$, $N_m = 1.831$, $N_p = 1.800$, $N_g - N_p = 0.046$. Color malachite to yellow-green with X = green, Y = yellow-green, Z = blue-green. Rare.

Libethenite $\{Cu_2(OH)PO_4\}$ is orthorhombic with $a : b : c = 0.960 : 1 : 0.702$. Crystals equant with imperfect 100 and 010 cleavages. H. = 4. G. = 3.7. F. = 2–2.5. Soluble in acid. Optic plane is 001; X = *b*. (−) 2V = 81°–85°, $\rho > v$ strong. $N_g = 1.789$, $N_m = 1.745$, $N_p = 1.702$, $N_g - N_p = 0.087$. Color olive-green, with X = pale green to yellow or bluish, Y = bright green to yellowish green, Z = pale green to yellow or bluish; often shows spots of different color. Found in oxide zone of copper deposits. Rare.

Adamite $\{Zn_2(OH)AsO_4\}$ is orthorhombic with $a : b : c = 0.973 : 1 : 0.716$. Crystals elongated parallel to *b*, or, rarely, to *c*. H. = 3.5. G. = 4.35. F. = 3. Soluble in HCl. Optic plane is 001; X = *a*. (+) 2V = 83°, $\rho < v$ strong, $N_m = 1.728$; also (−) 2V = 90°±, $\rho > v$, strong, $N_g = 1.758$, $N_m = 1.734$, $N_p = 1.708$, $N_g - N_p = 0.050$ (Larsen). Color yellow, green, pink, white. Colorless in section or pleochroic with maximum absorption parallel to X; in pink types X = carmine. Pink types contain cobalt up to 5 per cent. Found in the oxide zone of zinc deposits. Rare.

Descloizite $\{PbZn(OH)VO_4\}$ is orthorhombic with $a : b : c = 0.805 : 1 : 0.637$. Crystals pyramidal or short prismatic without cleavage. H. = 3.5. G. = 5.9–6.2. F. = 1.5. Soluble in dilute HNO_3. Optic plane is 010; X = *c*. (−) 2V = large (attaining 90° + ?), $\rho < v$ strong. $N_g = 2.35$, $N_m = 2.265$, $N_p = 2.185$, $N_g - N_p = 0.17$. Color red, brown, black, with X = pale yellow, Y = greenish yellow, Z = dark golden yellow. Found in the oxide zone of lead-zinc deposits. Uncommon. In the variety *cuprodescloizite* about half the zinc is replaced by copper; it has X parallel to fibers and (−) 2V = 50°–70°, $\rho > v$ strong. $N_g = 2.33$, $N_m = 2.26$–2.31, $N_p = 2.17$–2.21, $N_g - N_p = 0.12$–0.15. Color olive green to brown; in section yellow and faintly pleochroic or X = colorless, Y and Z = reddish brown. Rare. In *pyrobelonite*[18] all the Zn and part of the Pb are replaced by Mn; it has G. = 5.4. Optic plane is 001; X = *a*. (−) 2V = ?, N = high. Rare. The following microchemical test is decisive for descloizite according to Lacroix: the HNO_3 solution of the mineral evaporated to dryness leaves a crimson residue (V_2O_5) which, dissolved in dilute H_2SO_4 leaves the lead as sulphate; the decanted solution, saturated with sodium bicarbonate and evaporated, yields tetrahedrons of sodium-zinc bicarbonate.

Georgiadesite $(Pb_6Cl_6As_2O_8)$ is orthorhombic with $a : b : c = 0.577 : 1 : 0.223$. Crystals small pseudohexagonal without cleavage. H. = 3.5. G. = 7.1. F. = easy. Soluble in HNO_3. Optic plane is 100; X = *b*. (+) 2V = large. N is estimated at 2.1; $N_g - N_p$ = distinct. Color white to yellow. Found on lead slag at Laurium, Greece. Very rare.

Erinite $\{Cu_5(OH)_4As_2O_8\}$ is orthorhombic (?) with one perfect cleavage. H. = 5. G. = 4. F. = 2–2.5. Soluble in HNO_3. Y parallel to elongation; Z normal to cleavage. (−) 2V = medium, $\rho < v$ moderate. $N_g = 1.88$, $N_m = 1.86$, $N_p = 1.82$, $N_g - N_p = 0.06$. Color emerald green. Found in oxide zone of copper deposits. Very rare.

Wagnerite (Mg_2FPO_4) is monoclinic with $a : b : c = 1.915 : 1 : 1.506$, $\beta = 71° 53'$; crystals complex with imperfect 100 and 110 cleavages; prismatic cleavage angle = 57° 35′. H. = 5. G. = 3. F. = 4. Soluble in HCl. Optic plane is 010; $Z \wedge c = -21.5°$. (+) 2V = 26°±, $\rho > v$. $N_g = 1.582$, $N_m = 1.570$, $N_p = 1.569$, $N_g - N_p = 0.013$.

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[18] G. Flink: *Geol. För. Förh.*, XLI, 1919, p. 433.

Colorless, yellow, pink, greenish; colorless in section. Found in quartz veins in Austria. Very rare.

Triplite $\{(Mn,Fe)_2FPO_4\}$ is monoclinic with perfect 100 and imperfect 010 cleavages. H. = 4–4.5. G. = 3.58–3.79. F. = 2.5. Soluble in acid. Optic plane is 010; $Z \wedge a = 42°$. (+) 2V = very large, $\rho > v$ strong. With 1.68 FeO, 2.86 CaO, 1.21 MgO: $N_g = 1.672$, $N_m = 1.660$, $N_p = 1,650$, $N_g - N_p = 0.022$. With 4.95 FeO, 3.18 CaO, and 0.58 MgO: $N_g = 1.682$, $N_m = 1.673$, $N_p = 1.665$, $N_g - N_p = 0.017$. Color salmon-pink to brown with X > Y > Z. Found in pegmatite and quartz veins. Very rare.

Triploidite $\{(Mn,Fe)_2(OH)PO_4\}$ is monoclinic with $a : b : c = 1.857 : 1 : 1.494$, $\beta = 71° 46'$. Crystals prismatic with perfect 100 cleavage. H. = 5. G. = 3.7. F. = 1.5. Soluble in acid. Optic plane normal to 010; $Z \wedge c = -3°$ to $-4°$. (+) 2V = medium, $\rho > v$ extreme. $N_g = 1.730$, $N_m = 1.726$, $N_p = 1.725$, $N_g - N_p = 0.005$. Color yellowish to reddish brown; colorless in section. Found in pegmatite. Very rare.

Herderite $\{CaBe(F,OH)PO_4\}$ is monoclinic with $a : b : c = 0.631 : 1 : 0.427$, $\beta = 89° 54'$. Crystals short domatic parallel to a; twinning on 001. Poor 110 cleavage. H. = 5. G. = 3. F. = diff. Soluble in acid. Optic plane is 010; $Z \wedge c = -2.5°$. (−) 2V = 74°, $\rho > v$, with distinct inclined extinction. $N_g = 1.621$, $N_m = 1.612$, $N_p = 1.592$, $N_g - N_p = 0.029$. Color yellowish to greenish. Found in pegmatite. Very rare.

Adelite $\{CaMg(OH)AsO_4\}$ is monoclinic with $a : b : c = 1.099 : 1 : 1.564$, $\beta = 73° 14'$(?). Crystals basal tablets or prismatic without cleavage. H. = 5. G. = 3.75. F. = easy. Soluble in HNO_3. Optic plane is 010; $Z \wedge c = +39°$. (+) 2V = very large, $\rho < v$. $N_g = 1.731$, $N_m = 1.721$, $N_p = 1.712$, $N_g - N_p = 0.019$. Color gray. Found in manganese ore deposits. Very rare.

Chlorophoenicite[19] $\{10(Mn,Zn)O \cdot As_2O_5 \cdot 7H_2O\}$ is monoclinic with $a : b : c = 2.357 : 1 : 2.153$, $\beta = 74° 26'$. Crystals deeply striated and elongated parallel to b. Distinct 100 cleavage. H. = 3–3.5. G. = 3.55 (calc.). F. = 6, but blackens. The optic plane is 010 and an optic axis is nearly normal to 100. (−) 2V = 83°, $\rho > v$ strong. $N_g = 1.697$, $N_m = 1.690$, $N_p = 1.682$, $N_g - N_p = 0.015$. Color pale green in daylight and purplish-red in artificial light. Found with franklinite and willemite at Franklin, N. J. Very rare.

Tilasite $(CaMgFAsO_4)$ is monoclinic with $a : b : c$[20] $= 0.743 : 1 : 0.845$, $\beta = 59° 0'$. H. = 5. G. = 3.77. Soluble in acid. X normal to 010; $Z \wedge c = -30°$. Optic plane nearly normal to $\bar{1}01$. (−) 2V = 82° 14'. $N_g = 1.675$, $N_m = 1.660$, $N_p = 1.640$, $N_g - N_p = 0.035$. Color pale green to gray. Found in manganese deposits. Very rare.

Sarkinite $\{Mn_2(OH)AsO_4\}$ is monoclinic with $a : b : c = 2.001 : 1 : 1.515$, $\beta = 62° 14'$. Crystals with 100 and 001 faces well developed and distinct 100 cleavage. H. = 4–4.5. G. = 4.18. F. = 4. Soluble in HCl. Optic plane is 010; $Z \wedge c = +36°$ to $+43°$. (−) 2V = 83°, $\rho > v$ strong. $N_g = 1.802$, $N_m = 1.793$, $N_p = 1.780$, $N_g - N_p = 0.022$ (Larsen); $N_1 = 1.8085$, $N_2 = 1.8065$, $N_3 = 1.7930$, $N_1 - N_3 = 0.0155$ (Flink[21]). Color rose-red to yellow. Found in manganese deposits in Sweden. Very rare.

Clinoclasite $\{Cu_3(OH)_3AsO_4\}$ is monoclinic with $a : b : c = 1.907 : 1 : 3.851$, $\beta = 80° 30'$. Crystals prismatic or basal tablets with perfect 001 cleavage. H. = 3. G. = 4.19–4.38. F. = 2–2.5. Soluble in HNO_3. Optic plane is 010; Z near a. (−) 2V = 53°, $\rho < v$ very strong. $N_g = 1.91$, $N_m = 1.870$, $N_p = 1.73$, $N_g - N_p = 0.18$. Color black blue-green with X = pale blue-green. Y = light blue-green, Z = benzol-green. Found in oxide zone of copper deposits. Rare.

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[19] W. F. Foshag and R. B. Gage: *Jour. Wash. Acad. Sci.*, XIV, 1924, p. 362; *Proc. U. S. Nat. Mus.*, LXX, 1927, art. 20.

[20] G. Aminoff: *Geol. För. Förh.*, XLV, 1923, p. 144.

[21] *Geol. För. Förh.*, XLVI, 1924, p. 661.

Calciovolborthite {$CaCu(OH)VO_4$} is monoclinic (?) in rosettes and pseudohexagonal scales. H. = 3.5. F. = 1.5–3. Two varieties are known, a greenish yellow with one good cleavage with G. = 3.5, N = 1.92, and birefringent; and a yellowish green with (brownish streak and G. = 3.9? and) $N_g = 2.10$, $N_m = 2.05$, $N_p = 2.01$ in violet light, $N_g - N_p = 0.09$. (+) 2V = 68° Li, 83° Na, 89° Tl, negative in blue light. Extreme dispersion of bisectrices. The greenish yellow variety contains much As_2O_5 replacing V_2O_5. Found on sandstone in Utah. Very rare.

Pseudomalachite [22] {$(CuOH)_3PO_4$?} is monoclinic (?) in fibrous masses. H. = 4.5. G. = 3.6. F. = 2. Soluble in HNO_3. Fibers have nearly parallel extinction and positive elongation. (–) 2E = 95°, $N_g = 1.807$, N_m = ?, $N_p = 1.73$, $N_g - N_p = 0.077$. Color green. Found in ore deposits. Rare.

Spodiosite (Ca_2FPO_4) is triclinic (?) in flattened prisms with distinct 010 and indistinct 001 cleavages. Prism angle is 84°. H. = 5. G. = 2.94(?). F. = diff. Soluble in acid. Extinction angle [23] on one cleavage is 38° to other cleavage. (+) 2V = 69°, $\rho > v$ rather strong. $N_g = 1.699$, $N_m = 1.674$, $N_p = 1.663$, $N_g - N_p = 0.036$. Color ash-gray or brown. Found in Sweden. Very rare.

Tarbuttite {$Zn_2(OH)PO_4$} is triclinic with [illegible], $\beta = 123° 52'$, $\gamma = 87° 25'$. Crystals complex with perfect 001 cleavage. H. = 3.5–4. G. = 4.14. F. = easy. Soluble in HCl. Extinction on 010 is at 25° with 100 and 10° with 001; on 100 it is at 26° with 001 and 14° with 010; dispersion strong. (–) 2V = 50°; in one optic axis $\rho > v$ weak; in the other $\rho < v$. $N_g = 1.713$, $N_m = 1.705$, $N_p = 1.660$, $N_g - N_p = 0.053$. $N'_g - N'_p$ on 001 = 0.0145. Colorless to brownish. Found at the zinc mines of Broken Hill, Rhodesia. Very rare.

Dihydrite {$Cu_5(OH)_4PO_4$} is triclinic with $a : b : c = 2.825 : 1 : 1.534$, $\alpha = 89° 30'$, $\beta = 91° 1'$, $\gamma = 90° 40'$. Crystals monoclinic in habit, fibrous parallel to b, with imperfect 010 cleavage. Twinning on 100. H. = 4.5–5. G. = 4.0 4.4. F. = 2–2.5. Soluble in HCl. $X \wedge c = +22°$; Z near b. 2V = 90°±, $\rho > v$ strong. Some crystals +, others –. $N_g = 1.805$, $N_m = 1.762$, $N_p = 1.719$, $N_g - N_p = 0.086$. Color dark emerald green with X = greenish blue, Y = yellowish green, Z = pale yellowish brown and X > Z. Found in the Urals, etc. Uncommon. Differs from malachite in lack of effervescence with acid.

5. HYDROUS BASIC PHOSPHATES, ETC., OF DIVALENT BASES

Chalcophyllite {$10CuO \cdot As_2O_5 \cdot 12H_2O$(?) with some Al_2O_3 and SO_3} is trigonal with $c = 2.554$. Crystals basal tablets with perfect basal cleavage. H. = 2. G. = 2.5. F. = 2–2.5. Soluble in HNO_3. Uniaxial negative with $N_o = 1.632$, $N_e = 1.575$, $N_o - N_e = 0.057$ (Gaubert [24]). $N_o = 1.618$, $N_e = 1.552$, $N_o - N_e = 0.066$ (Shannon [25]); loses water easily with increase in indices; thus, after a few hours in a desiccator, $N_o = 1.680$, $N_e = 1.620$, $N_o - N_e = 0.060$. Color emerald green. Found in copper deposits. Very rare.

Conichalcite ($2CuO \cdot 2CaO \cdot As_2O_5 \cdot 1.5H_2O$) is orthorhombic and fibrous parallel to a. H. = 4.5. G. = 4.15. F. = 2.5–3. Soluble in acid. Optic plane is 010; X = c. (+) 2E = small (Larsen). (–) 2E = 88° (Michel [26]). (–) 2V = 25°, $\rho > v$ strong (Gillson [27]). $N_g = 1.801$, $N_m = 1.78$, $N_p = 1.778$, $N_g - N_p = 0.020$; also $N_g = 1.790$,

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[22] G. Césaro: *Ann. Soc. Geol. Belg. Bull.* XLV, 1922, pp. 102 and 176.

[23] Optic data by Larsen: *U. S. Geol. Surv. Bull.* 679, 1921, on unanalyzed material.

[24] *Bull. Soc. Fr. Min.*, XXVII, 1904, p. 223.

[25] *Am. Jour. Sci.*, CCVII, 1924, p. 31.

[26] *Bull. Soc. Fr. Min.*, XXXII, 1909, p. 51.

[27] *Am. Mineral.*, XI, 1926, p. 109

$N_m = 1.77$, $N_p = 1.765$, $N_g - N_p = 0.025$; also $N_g = 1.770$, $N_m = ?$, $N_p = 1.730$, $N_g - N_p = 0.040$ (Gillson). Elongation positive. Color apple to emerald green; in section pale green, not pleochroic, or X = yellowish to colorless, Y = pale greenish, Z = pale bluish green. Found in the oxide zone of copper deposits. Rare.

Leucochalcite ($4CuO \cdot As_2O_5 \cdot 3H_2O$) is orthorhombic and acicular parallel to *c*. F. = 2–2.5 to black glass. Y = *c* (Larsen); Z = *c* (Lacroix). (+) 2V = large, $\rho < v$ strong. $N_g = 1.84$, $N_m = 1.807$, $N_p = 1.79$, $N_g - N_p = 0.05$. Color white, silky. Found in the oxide zone of copper deposits. Very rare.

Hemafibrite $\{Mn_3(OH)_3AsO_4 \cdot H_2O\}$ is orthorhombic with $a : b : c = 0.526 : 1 : 1.150$. Crystals prismatic to fibrous with distinct 010 cleavage. H. = 3. G. = 3.6. F. = easy, to black bead. Soluble in HCl. Optic plane is 100; X = *b*. (+) 2V = 35°, $\rho > v$. $N_g = 1.93$, $N_m = 1.88$, $N_p = 1.87$, $N_g - N_p = 0.06$. Color brownish to garnet red; alters to black. In section red-brown, not pleochroic. Found in manganese mines in Sweden. Very rare.

Cornwallite ($5CuO \cdot As_2O_5 \cdot 3H_2O$) is orthorhombic (?), massive in finely fibrous spherulites. H. = 4.5. G. = 4.16. F. = 2–2.5. Optic plane seems to be normal to fibers. (+) 2V = small, $N_g = 1.85 \pm$, $N_m = 1.815 \pm$, $N_p = 1.81 \pm$, $N_g - N_p = 0.04 \pm$. Color deep green resembling malachite (but does not effervesce with acids). Found on olivenite. Very rare.

Euchroite $\{Cu_2(OH)AsO_4 \cdot 3H_2O\}$ is orthorhombic with $a : b : c = 0.609 : 1 : 1.038$. Crystals prismatic with vertical striations and difficult 110 and 011 cleavages. H. = 3.5–4. G. = 3.39. F. = 2–2.5. Soluble in HNO_3. Optic plane is 100; X = *b*. (+) 2V = 29°, $\rho > v$ moderate. $N_g = 1.733$, $N_m = 1.698$, $N_p = 1.695$, $N_g - N_p = 0.038$. Color emerald to leek green. In section bright bluish green, faintly or nonpleochroic. Found in slate in Hungary. Very rare.

Holdenite[27a] $\{12(Mn,Zn)O \cdot As_2O_5 \cdot 5H_2O\}$ is orthorhombic with $a : b : c = 0.380 : 1 : 0.276$. Crystals 100 tablets with indistinct 010 cleavage. H. = 4. G. = 4.07. The optic plane is 010; Z = *a*. (+) 2V = 30°, $\rho > v$ distinct. $N_g = 1.785$, $N_m = 1.770$, $N_p = 1.769$, $N_g - N_p = 0.016$. Color pink to red. Found with willemite calcite, etc., at Franklin, N. J. Very rare.

Tagilite $\{Cu_2(OH)PO_4 \cdot H_2O\}$ is monoclinic in fibrous concretions with distinct 010 cleavage. H. = 3–4. G. = 4.1. F. = 2–2.5. Soluble in acid. Elongation negative with small extinction angle. (−) 2V = small. $N_g = 1.85$, $N_m = 1.84$, $N_p = 1.69$, $N_g - N_p = 0.16$. Color green. Found on limonite. Very rare.

Spencerite $\{Zn_4(OH)_2P_2O_8 \cdot 3H_2O\}$ is monoclinic with very perfect 100, perfect 010, and imperfect 001 cleavages nearly at right angles. Lamellar twinning on 100. Crystal. 100 tablets. H. = 3. G. = 3.14. F. = easy. Soluble in acid. Optic plane normal to 010; $X \wedge c = 85° \pm$. Extinction in 010 is 6° from twinning lines. (−) 2V = 49°, $\rho > v$ moderate. $N_g = 1.602$, $N_m = 1.600$, $N_p = 1.586$, $N_g - N_p = 0.016$ (Larsen); $N_g = 1.606$, $N_m = 1.602$, $N_p = 1.586$, $N_g - N_p = 0.020$ (Walker and Parsons[28]). Colorless. Found in a zinc deposit near Salmo, B.C., with hemimorphite. Very rare.

Ludlamite ($7FeO \cdot 2P_2O_5 \cdot 9H_2O$) is monoclinic with $a : b : c = 2.253 : 1 : 1.982$, $\beta = 79° 27'$. Crystals basal tablets with perfect 001 and distinct 100 cleavages. H. = 3–4. G. = 3.72. F. = 2–2.5. Soluble in HCl. Optic plane is 010; $Z \wedge c = -67°$. (+) 2V = 82°, $\rho > v$ small. $N_g = 1.697$, $N_m = 1.675$, $N_p = 1.653$, $N_g - N_p = 0.044$ (Larsen); $N_g - N_p = 0.027$ (Buttgenbach[29]); $N_g = 1.689$, $N_m = 1.669$, $N_p = 1.650$, $N_g - N_p = 0.039$ (Berman[30]). Color bright green. Found in ore deposits. Very rare.

[27a] C. Palache and E. V. Shannon; *Am. Mineral.* XII, 1927, p. 144.

[28] *Univ. Toronto Studies, Geol. Ser.*, No. 12, 1921, p. 58.

[29] *Ann. Soc. Geol. Belg.*, XLII, 1919, p. 69 B.

[30] *Am. Mineral.*, X, 1925, p. 428.

Tsumebite ($4PbO \cdot 2CuO \cdot P_2O_5 \cdot nH_2O$) is monoclinic (or orthorhombic?) with $a : b : c = 0.977 : 1 : 0.879$, $\beta = 81° 44'$. Crystals basal plates. H. = 3.5. G. = 6.1. Soluble in HCl. (+) $2V = 89°$, $\rho < v$ strong. $N_g = 1.956$, $N_m = 1.920$, $N_p = 1.885$, $N_g - N_p = 0.071$. Color emerald green. Faintly absorptive with $X < Z$. Found in ore deposit in southwest Africa. Very rare.

Bayldonite $\{4(Pb,Cu)O \cdot As_2O_5 \cdot 2H_2O\}$ is monoclinic (?) and fibrous parallel to c. H. = 4.5. G. = 4.35. Fuses to black bead. Soluble in HNO_3. Optic plane normal to 010; $Z \wedge c = 45° \pm$. (+) 2V = large, $\rho < v$ strong(?). $N_g = 1.99$, $N_m = 1.97$, $N_p = 1.95$, $N_g - N_p = 0.04$. Color grass green. Found in Cornwall. Very rare.

Isoclasite $\{Ca_2(OH)PO_4 \cdot 2H_2O\}$ is monoclinic in vertical needles with perfect 010 cleavage. H. = 1.5. G. = 2.9. Fuses. Soluble in HCl. Optic plane is 010; $Z \wedge c$ = small. (+) $2V = 50° \pm$. $N_g = 1.580$, $N_m = 1.568$, $N_p = 1.565$, $N_g - N_p = 0.015$. Color white. Found with siderite. Very rare.

Volborthite $\{6(Cu,Ca,Ba)O \cdot V_2O_5 \cdot 15H_2O\}$ is monoclinic (?) in six-sided tablets with one perfect cleavage. H. = 3. G. = 3.55. F. = 1.5(?). X or Z nearly normal to plates with strong dispersion. (±) 2V = large to small, $\rho > v$ very strong. $N_g = 2.02$, $N_m = 2.01$, $N_p = 2.00$, $N_g - N_p = 0.02$. Color olive-green to lemon yellow. Found in mines in the Urals. Very rare.

Veszelyite $\{7(Zn,Cu)O \cdot (P,As)_2O_5 \cdot 9H_2O\}$ is (monoclinic ? or) triclinic with $a : b : c = 0.71 : 1 : 0.91$, $\alpha = 89° 31'$, $\beta = 103° 50'$, $\gamma = 89° 34'$. H. = 3.5-4. G. = 3.53. Fusible. (+) $2V = 71°$, $\rho < v$ very strong. $N_g = 1.695$, $N_m = 1.658$, $N_p = 1.640$, $N_g - N_p = 0.055$. Color greenish blue; paler and not pleochroic in section. Found on granite and limonite. Very rare.

A very similar mineral[31] found in Rhodesia is monoclinic with $a : b : c = 0.71 : 1 : 0.95$, $\beta = 76\frac{1}{3}°$. No good cleavage. H. = 3.5-4. G. > 3.33. Soluble in HCl. Optic plane is 010; $Z \wedge c = -33°$. (+) $2H = 43°$, $\rho < v$, $N_m = 1.63 \pm$, $N_g - N_p$ = strong. Color a fine blue, not pleochroic. Lamellar twinning. Rare.

Arakawaite[32] ($4CuO \cdot 2ZnO \cdot P_2O_5 \cdot 6\frac{1}{2}H_2O$) is much like the Rhodesian mineral and veszelyite. It is monoclinic with $a : b : c = 0.750 : 1 : 1.024$, $\beta = 70\frac{1}{2}°$. H = 3.5. G. = 3.09. Optic plane is 010; $Z \wedge c = -36°$. (+) $2V = 38\frac{1}{2}°$, $N_g = 1.658$, $N_m = 1.622$, $N_p = 1.618$, $N_g - N_p = 0.040$. Color dark bluish green. Found in ore deposits. Rare.

6. ANHYDROUS NORMAL PHOSPHATES, ETC., OF TRIVALENT BASES

XENOTIMITE (*Xenotime*) TETRAGONAL $c = 0.619$ YPO_4

COMP.—Yttrium may be replaced, in part, by Er, Ce, etc., silicon and thorium may be present in small amount.

PHYS. CHAR.—Crystals prismatic like zircon; twinning on 101. Perfect 110 cleavage. H. = 4-5. G. = 4.59. F. = 7. Insoluble in HCl.

OPT. PROP.—Uniaxial positive with $N_o = 1.7207$ Na, $N_e = 1.8155$, $N_e - N_o = 0.0948$.

Color yellowish brown to red, gray, yellow. Streak paler. Luster resinous to vitreous. In thin section colorless, yellowish, brownish; may be weakly pleochroic with X = pink or light yellowish brown, Z = brownish yellow or grayish brown.

OCCUR.—In pegmatite and granite, commonly associated with zircon.

DIAG.—Xenotimite differs from zircon in hardness and composition; from cassiterite in weaker refringence and from octahedrite in sign.

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[31] F. P. Mennell: *Mineral Mag.*, XIX, 1920, p. 69.

[32] K. Komada: *Min. Abst.*, I, 1921, p. 250; R. Ohashi: *Mineral. Abst.*, II, 1925, p. 380.

Pucherite ($BiVO_4$) is orthorhombic with $a : b : c = 1.096 : 1 : 0.939$. Crystals thick basal tablets or acicular with perfect 001 cleavage. H. = 4. G. = 6.25. F. = 2. Soluble in HCl. $X = c$, $Z = b$. $(-)\ 2V = 19°$, $\rho < v$ extreme. $N_g = 2.51$. $N_m = 2.50$, $N_p = 2.41$, $N_g - N_p = 0.10$ Li. Color reddish brown. Found in ore deposits. Very rare.

MONAZITE MONO. $a : b : c = 0.969 : 1 : 0.915$ $\beta = 76° 6'$ $CePO_4$

COMP.—Cerium may be replaced by more or less La, Di, Er, etc.; Th and Si also present, perhaps as $ThSiO_4$.

PHYS. CHAR.—Crystals small 100 tablets or elongated parallel to b or $\bar{1}11$; granular in sands. Perfect 001, distinct 100, and difficult 010 cleavages. Twinning on 100. H. = 5. G. = 5.1 ±. F. = 7. Difficultly soluble in HCl.

OPT. PROP.—The optic plane is normal to 010; Z makes an angle of 2°–6° with c in the obtuse angle β. For example, an accurate measure on monazite from Brazil gave Busz:[33] $Z \wedge c = +3° 38'$ Na. The relief is high and birefringence very strong. Dispersion $\rho < v$, very weak, varying to $\rho > v$, very weak; also weak horizontal dispersion. $(+)\ 2V = 6°–19°$ Na, $N_g = 1.837–1.849$, $N_m = 1.788–1.801$, $N_p = 1.787–1.800$, $N_g - N_p = 0.045–0.055$.

Color yellowish to reddish brown or red; pleochroism absent in thin section, but absorption is distinct with $Y > X = Z$.

OCCUR.—Sparse in tiny crystals in some granite, aplite, pegmatite, and gneiss. Also in sands derived from such rocks.

DIAG.—Differs from olivine in its very small optic angle; from titanite in its much weaker birefringence and very slight dispersion. In sands it may be distinguished from zircon by its yellow color, (weak) pleochroism in yellow, and biaxial character; and from epidote by weaker pleochroism and small optic angle.

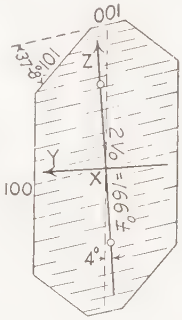

FIG. 75.—Optic orientation of monazite.

7. HYDROUS NORMAL PHOSPHATES, ETC., OF TRIVALENT BASES

Rhabdophanite {$(La,Di,Y,Er)PO_4 \cdot H_2O$} is tetragonal or hexagonal, fibrous. H. = 3.5. G. = 4. F. = 7. Soluble in acid. Uniaxial positive with $N_o = 1.654$, $N_e = 1.703$, $N_e - N_o = 0.049$. Color brown to white. Resembles brown sphalerite. Found in Cornwall. Very rare.

SCORODITE ORTHORHOMBIC $a : b : c = 0.866 : 1 : 0.954$ $FeAsO_4 \cdot 2H_2O$

PHYS. CHAR.—Crystals pyramidal, prismatic, or 100 tablets. Imperfect 120 cleavage. H. = 3.5–4. G. = 3.1–3.3. F. = 2–2.5. Soluble in HCl.

OPT. PROP.—The optic plane is 100; $X = b$. The following variations (given by Larsen) are probably due to isomorphous replacements.

$(+)\ 2V$	Dispersion	N_g	N_m	N_p	$N_g - N_p$	Locality
70°	$\rho > v$, strong	1.812	1.793	1.784	0.028	Laurium, Greece
....	....	.....	1.785	.....	.....	Red Mt., Colo.
62°	$\rho > v$, strong	1.797	1.774	1.765	0.032	Nassau, Germany
Med.	$\rho > v$, strong	1.765	1.742	1.738	0.027	Black Pine, Ida. (With 4.80 P_2O_5)

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[33] *N. Jahrb. Min. Beil. Bd.*, XXXIX, 1914, p. 489.

Crystals from Cornwall are reported to be negative with 2V = very large, $\rho > v$ strong, $N_g = 1.74$, and positive elongation.

Color leek green to brown; weakly pleochroic in thick sections with X = bluish green, Z = colorless to pink.

OCCUR.—With arsenopyrite, enargite, limonite, etc., in limestone; also in oxide zone in veins; also about geysers. Not common.

DIAG.—The color and the strong dispersion are rather characteristic.

STRENGITE ORTHORHOMBIC $a : b : c = 0.866 : 1 : 0.978$ $FePO_4 \cdot 2H_2O$

PHYS. CHAR.—Crystals pyramidal or macrodomatic with perfect 001 and imperfect 100 cleavages. H. = 3-4. G. = 2.87. F. = 2.5-3. Soluble in HCl, but not in H_2SO_4.

OPT. PROP.—The optic plane is 100; X = b (Larsen); Z = c, X = a (Laubmann[34]). Optic angle small with variable but strong dispersion, $\rho > v$ or $\rho < v$. The following variations are probably due to isomorphous replacements.

Sign	2V	N_g	N_m	N_p	$N_g - N_p$	Locality
(+)	29°	1.762	1.732	1.730	0.032	Lexington, Va.
(+)	Very small	1.745	1.708	1.708	0.037	Giessen, Germany
(−)	....	.....	1.74 ± (N_g?)	.....	Strong	Haute-Vienne, France[35]
		1.735	......	1.71	0.025	Giessen, Germany[36]
		1.730	......	1.710	0.020	Angelard, France (*Angelardite*)
(−)	Med.	1.722	1.714	1.697	0.025	Pala, Calif. (Blue manganiferous strengite)

Strengite from a pegmatite in Bavaria[34] has perfect basal cleavage and the optic plane parallel to 010 with (+) 2E = 30½° Li, 46° yellow, 55° green, 110° blue.

Color pink, carmine, white; colorless in section or weakly pleochroic with X and Y = colorless, Z = pale pink. Also blue or violet (when manganiferous) with X = colorless or very pale violet, Y = clear violet, Z = dark blue.

OCCUR.—In the oxide zone of iron deposits; in magnetite; and in pegmatite.[36]

DIAG.—The pink color and strong dispersion are rather characteristic; phosphosiderite has similar dispersion, but in it the optic angle is large and the maximum absorption is parallel to X.

Barrandite $\{(Al,Fe)PO_4 \cdot 2H_2O\}$ is orthorhombic and fibrous parallel to c. H. = 4.5. G. = 2.6 ±. Z = c. (+) 2V = large, $\rho > v$ strong. $N_m = 1.65 \pm$, $N_g - N_p = 0.03$ (Larsen). (+) 2V = moderate, $\rho > v$. $N_m = 1.57$-1.58, $N_g - N_p = 0.015$-0.017 (Lacroix). With $Fe_2O_3 = 30.0$ and $Al_2O_3 = 8.2$, N = 1.64 and $N_g - N_p = 0.02$ (Shannon[37]). Color gray, yellow, red, bluish, green. Intermediate in composition and properties between strengite and variscite. Found in Bohemia in sandstone. Very rare.

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[34] Zeit. Kryst. LV, 1920, p. 523.

[35] Described by Lacroix (*Minéral., France*, IV, 1910, p. 477) under the name *vilatéite*; it is a manganiferous strengite which is monoclinic with $\beta = 89° 27'$, but optically it seems to be orthorhombic, or very nearly so, as noted first by Lacroix.

[36] W. T. Schaller: *U. S. Geol. Survey Bull.* 610, 1916, p. 162.

[37] *Am. Mineral.*, VIII, 1923, p. 182.

VARISCITE ORTH. $a : b : c = 0.873 : 1 : 0.979$ $AlPO_4 \cdot 2H_2O$

PHYS. CHAR.—Crystals pyramidal; also often fibrous. H. = 4. G. = 2.54. F. = 7. Soluble in HCl after ignition.

OPT. PROP.—(−) $2V = 50°–60°$; $\rho > v$. Other optic data somewhat conflicting as follows:

	Lacroix [38]	Larsen & Schaller [39]	Gordon [40]
Optic plane =	010	?	100
X =	*a*	?	*b*
N_g =		1.570–1.594	1.610
N_m =	1.576–9	1.565–1.580	1.595
N_p =		1.550–1.570	1.575
$N_g - N_p$ =	> quartz	0.020–0.030	0.035

Color green, blue, yellow, white; colorless in section. On gentle heating the mineral loses water and then has $N_g = 1.450$, $N_m = 1.448$, $N_p = 1.447$, $N_g - N_p = 0.003$; the crystals are then lavender and strongly pleochroic with *a* (= Z) = lavender, *b* = pinkish lavender, *c* = violet; the sign is probably positive and 2V large.

OCCUR.—In chert in limestone in Utah. Rare.

Metavariscite [39] ($AlPO_4 \cdot 2H_2O$) is orthorhombic with $a : b : c = 0.894 : 1 : 1.092$. Crystals prismatic or 010 laths. H. = 4. G. = 2.54. Soluble in HCl after ignition. Optic plane is 010; X parallel to elongation (*a*). (+) $2V = 55° \pm$, $\rho < v$ distinct. $N_g = 1.582$, $N_m = 1.558$, $N_p = 1.551$, $N_g - N_p = 0.031$. Color green, blue, white; colored irregularly, with X = colorless, Y = Z = pale green. On gentle heating the mineral loses water and changes to the same substance thus obtained from variscite. Found only at Lucin, Utah, where it alters to variscite.

Kreuzbergite [34] (hydrated aluminum phosphate) is orthorhombic with $a : b : c = 0.394 : 1 : 0.526$, and 001(?) cleavage. G. = 2.14. Optic plane is 001; obtuse bisectrix, probably X, normal to cleavage. 2V nearly 90°, N = 1.62, $N_g - N_p = 0.02$ to 0.025. Found at Kreuzberg, Bavaria. Very rare.

Purpurite $\{(Mn,Fe)PO_4 \cdot \frac{1}{2}H_2O\}$ is orthorhombic with perfect 001 and imperfect 010 cleavages. H. = 4–4.5. G. = 3.4. F. = easy. Soluble in acid. Optic plane is 100; X = *c*. (+) $2V = 38° \pm$, dispersion very strong. $N_g = 1.92 \pm$, $N_m = 1.86 \pm$ to $1.92 \pm$, $N_p = 1.85 \pm$, $N_g - N_p = 0.04–0.07$. Color deep red or purple and strongly pleochroic with X = dark brownish gray or grayish, Y = scarlet or blood red, Z = purple or blood red. An alteration product of lithiophilite. Rare.

Heterosite $\{(Fe,Mn)PO_4 \cdot \frac{1}{2}H_2O\}$ is orthorhombic with perfect 001 and imperfect 010 and 100 cleavages. H. = 3.5–4. G. = 3.27–3.52. Fuses to deep brown enamel. Soluble in HCl. Optic plane is 100; X = *c*. (−) 2V = large. $N_g = 1.91$, $N_m = 1.89 \pm$, $N_p = 1.86$, $N_g - N_p = 0.05$. In lighter colored parts N_m may be as low as 1.84, and $N_g - N_p$ as low as 0.03. Another sample has: $N_m = 1.84–1.87$, $N_g - N_p = 0.03$. Color black or dark violet; strongly pleochroic with X = gray, brown, or reddish brown, Y = deep red or carmine (like hematite), Z = very dark violet or dark red. An alteration product of triplite. Rare.

Pseudoheterosite is closely associated with heterosite, and probably very similar in composition. In it the optic plane is 001 and X = brownish yellow, Y = dark brown, Z = golden yellow. 2V is apparently nearly 90°. Rare.

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[38] *Minéral., France*, IV, 1910, p. 479.

[39] *Am. Mineral.*, X, 1925, p. 23. *Peganite* and *lucinite* are regarded as synonyms of variscite.

[40] Personal communication, Dec. 17, 1924.

Zepharovichite ($AlPO_4 \cdot 3H_2O$) is cryptocrystalline fibrous. H. = 5.5. G. = 2.37. F. = 7. Soluble in HCl. Elongation positive, $N_m = 1.55$, $N_g - N_p = 0.02$. Color gray, greenish, yellowish. Found in sandstone in Bohemia. Very rare. Perhaps the same as wavellite.

Koninckite ($FePO_4 \cdot 3H_2O$) is in fibrous crusts with transverse cleavage. H. = 3. G. = 2.3–2.5. F. = 2.5–3. Soluble in HCl. Elongation negative and extinction parallel. $N_g = 1.656$, $N_m = 1.65 \pm$, $N_p = 1.645$, $N_g - N_p = 0.011$. Also isotropic with $N = 1.65$. Color yellow. Found in Belgium. Very rare.

Liskeardite $\{(Al,Fe)AsO_4 \cdot 8H_2O\}$ is orthorhombic (?) in fibrous crusts with good 010 cleavage. H. = 4 ±. G. = 3. F. = 7. Insoluble in HNO_3. Optic plane normal to 010; $Z = c$ (Larsen); $Z \wedge 001 = 70° \pm$ (Lacroix). (+) $2V$ = near 90° (Larsen). (−) $2E = 115°$ (Lacroix). $N_g = 1.689$, $N_m = 1.675$, $N_p = 1.661$, $N_g - N_p = 0.028$. Color white. Found in the oxide zone of metalliferous veins in Cornwall. Very rare.

Weinschenkite $\{(Er,Y)PO_4 \cdot 2H_2O\}$ is monoclinic[41] and acicular with $a : b = 0.969 : 1$ and $\beta = 47°$. F. = 7. Soluble in acid. Optic plane normal to 010; $Z \wedge c = +28°$. (+) $2V$ = moderate, $N = 1.6 \pm$, $N_g - N_p = 0.03 \pm$. Colorless. Found in iron ores in Bavaria.

Phosphosiderite [41a] ($4FePO_4 \cdot 7H_2O$) is monoclinic with $a : b : c = 0.545 : 1 : 0.897$, $\beta = 89° 24'$. Crystals prismatic or 010 tablets with perfect 010 and distinct 001 cleavages. Twinning on 101. H. = 3.5–4. G. = 2.76. F. = easy. Soluble in HCl. The optic plane is 010; $X \wedge c = +3°$ to $+5°$. (−) $2V = 62°$ Na, $\rho > v$ strong. $N_g = 1.738$, $N_m = 1.725$ (1.732), $N_p = 1.692$, $N_g - N_p = 0.046$. Color pinkish red to reddish violet with X = pale rose, Y = carmine red, Z = nearly colorless in thick plates; colorless in thin section. Found in iron ore and in pegmatite. Very rare.

8. ANHYDROUS BASIC PHOSPHATES, ETC., OF TRIVALENT BASES

Florencite $\{AlCeP_2O_8 \cdot 2Al(OH)_3\}$ is trigonal with $c = 1.159$, related to hamlinite and alunite. Crystals rhombohedral with good basal cleavage. H. = 5. G. = 3.59. F. = 7. Partly soluble in HCl. Uniaxial positive with $N_o = 1.680 \pm$, $N_e = 1.685$, $N_e - N_o = 0.005 \pm$. Color brown, yellow, red. Found in schists and placer sands in Brazil. Very rare.

Dufrenite $\{Fe_2(OH)_3PO_4\}$ is monoclinic (?). Crystals rare, fibrous or lamellar, with perfect 010 and distinct 100 cleavages. H. = 3.5–4. G. = 3.2–3.4. F. = 2.5. Soluble in acid. Optic plane is 100; $X = c$. Crystals show zonal growths and wide variations in the optic angle and extreme dispersion. In some crystals $2V$ about Z exceeds 90° (but not much), with $\rho < v$, strong. $N_g = 1.885$, $N_m = 1.840$, $N_p = 1.830$, $N_g - N_p = 0.055$. Cleavage pieces show no extinction in white light, but abnormal green, orange and red interference colors over a wide angle; fibers turned normal to Y show sharp parallel extinction. Color green, or, by alteration, yellow or brown. Strongly pleochroic with X = dark reddish brown or golden yellow, Y = pale yellowish or brownish yellow, Z = bright green (brownish in crystals with $2V$ = small). In another type (*kraurite*) the optic plane is 001; $X = a$. (+) $2V = 28°$ Na, 0° red. $N_g = 1.890$, $N_m = 1.845$, $N_p = 1.840$, $N_g - N_p = 0.050$. Color dark green; strongly pleochroic with X = pale yellowish, Y = rather dark reddish brown varying to bright green as $2V$ becomes small, Z = dark reddish brown to dark green. Found in iron ore deposits and in pegmatites. Rare.

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[41] H. Laubmann: *Geog. Jahrb. Geol. Landes. München*, XXXV, 1922, p. 193; *Min. Abst.* II, 1925, p. 522.

[41a] M. de Angelis: *Min. Abst.*, III, 1926, p. 210; *Zeit. Kryst.*, LV, 1920, p. 523.

Augelite $\{Al_2(OH)_3PO_4\}$ is monoclinic with $a : b : c = 1.642 : 1 : 1.271$, $\beta = 67° 34'$. Crystals basal or 110 tablets or prismatic with perfect 110 and good 101 cleavages. H. = 5. G. = 2.7. F. = 7. Nearly insoluble. Optic plane is 010. $Z \wedge c = -34°$. (+) $2V = 51°$. $N_g = 1.5877$, $N_m = 1.5759$, $N_p = 1.5736$, $N_g - N_p = 0.0141$. Colorless. Found in ore deposits. Very rare.

Atelestite $(3Bi_2O_3 \cdot As_2O_5 \cdot 2H_2O)$ is monoclinic with $a : b : c = 0.933 : 1 : 1.505$, $\beta = 80° 43'$. Indistinct 001 cleavage. H. = 3–4.5. G. = 6.4. F. = 1.5. (+) $2V = 44°$, $\rho < v$, rather strong. $N_g = 2.18$, $N_m = 2.15$, $N_p = 2.14$, $N_g - N_p = 0.04$. Color sulphur yellow. Found in a mine in Saxony. Very rare.

9. HYDROUS BASIC PHOSPHATES, ETC., OF TRIVALENT BASES

PHARMACOSIDERITE Pseudoisometric $Fe_3(OH)_3P_2O_8 \cdot 5H_2O$

Phys. Char.—Crystals cubes with tetrahedrons and imperfect cubic cleavage. H. = 2.5. G. = 3.0. F. = 1. Soluble in HCl.

Opt. Prop.—Nearly isotropic with N = 1.676 (Gaubert); 1.693 (Larsen); but anisotropic at ordinary temperature with $N_g - N_p = 0.005$. Sections parallel to cubic faces are divided into four segments by diagonals, or into one central square area and four bordering segments, the latter having in some cases lamellar twinning parallel to the edges. (−) 2V = small to moderate, $\rho > v$, very strong, with or without strong dispersion of bisectrices resulting in abnormal interference colors. Some fragments are optically positive. In bordering segments extinction is parallel to the edges (Lacroix) or at large angles (Larsen). On heating, the border zones change, the indices gradually become equal (isotropic) and then change places. The anisotropic crystals are probably monoclinic with the optic plane parallel to 010 (Larsen).

Color green, yellow, brown. Crystals quickly absorb NH_4OH, becoming red; then in dilute HCl they take on their original color again.

Occur.—In the oxide zone of copper and tin deposits from the alteration of arsenopyrite, enargite, etc. Uncommon.

Diag.—The cubic form and optic properties are characteristic.

Cacoxenite $\{Fe_2(OH)_3PO_4 \cdot 4.5H_2O\}$ is hexagonal (Larsen) or orthorhombic (Lacroix). Fibrous. H. = 3–4. G. = 3.38. F. = 2.5–3. Soluble in HCl. Uniaxial positive with $N_o = 1.580–1.585$, $N_e = 1.640–1.656$, $N_e - N_o = 0.060–0.071$ (Larsen). Color yellow, becoming darker when exposed to air. Distinctly pleochroic with X = pale yellowish, Z = orange to canary yellow, and X < Z. Found in iron ore deposits and in pegmatite.[42] Rare.

Ceruleolactite $(3Al_2O_3 \cdot 2P_2O_5 \cdot 10H_2O)$ is fibrous in crusts. H. = 5. G. = 2.55–2.7. F. = 7. Soluble in HCl. Uniaxial positive with $N_o = 1.580$, $N_e = 1.588$, $N_e - N_o = 0.008$. Color white to light blue. Found in oxide zone of ore deposits. Very rare.

WAVELLITE Orthorhombic $Al_3(OH)_3P_2O_8 \cdot 5H_2O$

$a : b : c = 0.564 : 1 : 0.408$

Phys. Char.—Crystals very rare; fibrous, radiated. Good 110 and 010 cleavages. H. = 3.5–4. G. = 2.33. F. = 7, but swells and gives green flame color. Soluble in HCl.

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[42] Laubmann and Steinmetz: *Zeit. Kryst.*, LV, 1920, pp. 553, 565, 577, 579; $Z \wedge c$ given as 8°.

Opt. Prop.—The optic plane is 100; Z = c. Elongation positive. (+) 2V = 72°, $\rho > v$, weak; $N_g = 1.552$, $N_m = 1.534$, $N_p = 1.525$, $N_g - N_p = 0.027$ (Larsen); $N_g = 1.545$ (Slavik[43]); $N_m = 1.526$ (Des Cloizeaux); $N_g = 1.545$, $N_m = 1.534$, $N_p = 1.525$, $N_g - N_p = 0.020$ (Shannon[44]). Color white, yellow, pink, green, brown, black; colorless in section.

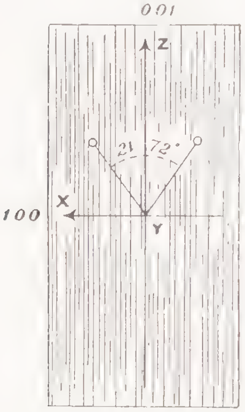

Fig. 76.—Optic orientation of wavellite.

Occur.—In pegmatites and veins; also in phyllites. Uncommon.

Diag.—Characterized by radiated fibrous structure and optic characters.

Spherite ($5Al_2O_3 \cdot 2P_2O_5 \cdot 16H_2O$) is orthorhombic in fibrous concretions with one distinct cleavage. H. = 4. G. = 2.54. F. = 7. According to Slavik,[43] elongation negative with N (normal to elongation) = 1.575, $N_p = 1.563$. According to Larsen, elongation positive with $N_g = 1.588$, $N_m = 1.576$, $N_p = 1.562$, $N_g - N_p = 0.026$. Color white to bluish, colorless in section. Found in hematite in schists. Very rare.

Vashegyite ($4Al_2O_3 \cdot 3P_2O_5 \cdot 30H_2O$) is fibrous. H. = 2–3. G. = 1.96. F. = 7. Soluble in acid. Positive elongation. N = 1.48, $N_g - N_p = 0.02$. Also amorphous with N = 1.49; also 1.504.[45] Colorless. Found in iron ore deposits. Very rare.

Beraunite $\{Fe_3(OH)_3P_2O_8 \cdot 2 \cdot 5H_2O\}$ is monoclinic with $a : b : c = 2.754 : 1 : 4.016$, $\beta = 48° 33'$. Crystals 100 tablets with distinct 100 cleavage. H. = 2. G. = 2.87–2.98. Soluble in HCl. Optic plane is normal to 010; $X \wedge c = 88.5°$. (+) 2V = medium, $\rho > v$ marked. $N_g = 1.815$, $N_m = 1.786$, $N_p = 1.775$, $N_g - N_p = 0.040$ (Larsen); also reported[42] as: Z = b, $Y \wedge c = 5°$, N = 1.65 ±, $N_g - N_p = 0.02$ ±. Color reddish brown to hyacinth red with X = Y = pale flesh color to colorless, Z = carnelian red to vinaceous. Found in iron ore deposits. Rare.

Delvauxite[31] ($2Fe_2O_3 \cdot P_2O_5 \cdot 20H_2O$?) is apparently amorphous with H. = 2.5. G. = 1.82–2.0. Isotropic with N = 1.72 ±. Color chestnut brown. Found in concretionary masses. Rare.

Picite ($3Fe_2O_3 \cdot 2P_2O_5 \cdot 10H_2O$?) is apparently amorphous with H. = 3–4. G. = 2.83. Isotropic[46] with N = 1.64. Color dark brown; streak yellow. Rare.

Evansite ($3Al_2O_3 \cdot P_2O_5 . 18H_2O$) is apparently amorphous in concretions. H. = 4. G. = 1.94. F. = 7. Soluble in hot H_2SO_4. Isotropic with N = 1.485. Colorless. Found on limonite in Hungary. Very rare.

Rosiéresite (hydrous phosphate of Al, Pb, Cu) is related to evansite; apparently amorphous. G. = 2.2. F. = 7, but blackens. Soluble in HNO_3. Isotropic with N = 1.5. Color yellow. Found as stalactites in an abandoned copper mine. Very rare.

Planerite ($3Al_2O_3 \cdot 2P_2O_5 \cdot 18 \pm H_2O$) is apparently amorphous. H. = 2–5. G. = 2.65. Slightly soluble in acid. Isotropic with N = 1.517. Also in part birefringent. Color green. Found in copper mines in the Urals. Very rare.

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[43] *Bull. Intern. Acad. Bohème*, XXII, 1918, p. 32; *Min. Abst.*, I, 1921, p. 290.

[44] *Proc. U. S. Nat. Mus.*, LXII, 1922, pt. 9.

[45] F. Ulrich: *Min. Abst.*, II, 1923, p. 141.

[46] F. Slavik: *Tables Ann. Intern. Const.*, V, 1925.

10. HYDROUS PHOSPHATES, ETC., CONTAINING TETRAVALENT OR PENTAVALENT BASES

URANITE GROUP

The minerals of the uranite group are pseudotetragonal (orthorhombic and monoclinic) phosphates and arsenates of uranium with copper, calcium or barium. The following types are known:

Torbernite	$Cu(UO_2)_2P_2O_8 \cdot 12H_2O$	Metatorbernite	$Cu(UO_2)_2P_2O_8 \cdot 8H_2O$
Zeunerite	$Cu(UO_2)_2As_2O_8 \cdot 12(?)H_2O$	Metazeunerite	$Cu(UO_2)_2As_2O_8 \cdot 8(?)H_2O$
Uranospathite	$Ca(UO_2)_2P_2O_8 \cdot 12H_2O$	Autunite	$Ca(UO_2)_2P_2O_8 \cdot 8H_2O$
Uranospinite	$Ca(UO_2)_2As_2O_8 \cdot 12(?)H_2O$		
Uranocircite	$Ba(UO_2)_2As_2O_8 \cdot 12(?)H_2O$		
Troegerite	$(UO_2)_3As_2O_8 \cdot 12H_2O$		

Phosphuranylite $\{(UO_2)_3P_2O_8 \cdot 6(?)H_2O\}$, tyuyamunite $\{Ca(UO_2)_2V_2O_8 \cdot 4 \pm H_2O?\}$, sincosite $\{Ca(VO)_2P_2O_8 \cdot 5H_2O?\}$, and carnotite $\{K_2(UO_2)_2V_2O_8 \cdot 4 \pm H_2O?\}$ seem to be related to this group.

Torbernite $\{Cu(UO_2)_2P_2O_8 \cdot 12H_2O\}$ is orthorhombic (and pseudotetragonal) with $a : b : c = 1 \pm : 1 : 2.97$. Crystals square basal tablets, pyramidal, or micaceous masses, with perfect 001 and distinct 100 cleavages. H. = 2–2.5. G. = 3.22. F. = 2.5. Soluble in HNO_3. Nearly uniaxial and negative with $N_o = 1.592$, $N_e = 1.582$, $N_o - N_e = 0.010$. Color light to dark green with X = pale green or pale blue, Y = Z = greenish yellow and X < Y = Z. The mineral shows five well-defined absorption bands between 440 and 510 $\mu\mu$. Found in veins in schists and granite. Rare.

Metatorbernite $\{Cu(UO_2)_2P_2O_8 \cdot 8H_2O\}$ is also pseudotetragonal with $c = 2.28$. Crystals square basal tablets with perfect 001 and distinct 100 cleavages. H. = 2.5. G. = 3.67. F. = 2.5. Soluble in HNO_3. Nearly uniaxial and positive (in white light) with abnormal dispersion of the indices, thus:[47]

$\lambda =$	640 $\mu\mu$	589 $\mu\mu$	550 $\mu\mu$	515 $\mu\mu$	480 $\mu\mu$	440 $\mu\mu$
$N_o =$	1.619	1.624	1.629	1.6335	1.640	1.6495
$N_e =$	1.622(5)	1.626	1.630	1.6335	1.638	1.6465
$N_e - N_o =$	0.003(5)	0.002	0.001	0.0000	(−) 0.002	(−) 0.003

The mineral is therefore isotropic in green light (515 $\mu\mu$), positive in red and yellow light, and negative in blue light. The interference colors are quite abnormal, being confined to red and blue. Stoces[48] reports $N_m = 1.610$ to 1.628 and 2E = very small to 30° in different samples. Color emerald to grass green with X = pale blue, Z = green. Metatorbernite is easily formed by dehydration of torbernite which occurs at 60°–65° C. It is found in Cornwall and Spain. Hallimond[49] argues that the dehydration occurs only through vertical faces and not through the base; he thinks the water exists between basal layers of atoms, and the change in axial ratio is in harmony with this view.

Zeunerite $\{Cu(UO_2)_2As_2O_8 \cdot 12(?)H_2O\}$ is pseudotetragonal with $c = 2.91$. Crystals basal tablets with perfect 001 and good 100 cleavage. H. = 2–2.5. G. = 3.2. F. = 3. Soluble in HNO_3. Nearly uniaxial and negative with $N_o = 1.643$, $N_e = 1.623$, $N_o - N_e = 0.020$. Color apple to emerald green; pale green in section with X < Z. Found on quartz with copper ores. Rare.

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[47] From the graph of N. L. Bowen: *Am. Jour. Sc.*, CXCVIII, 1919, p. 195.

[48] *Roz. Ceské Akad.*, XXVII, 1918, No. 27; *Min. Abst.*, I, 1922, p. 291.

[49] *Mineral. Mag.*, XVII, 1916, p. 326; XIX, 1920, p. 43.

Metazeunerite $\{Cu(UO_2)_2As_2O_8 \cdot 8(?)H_2O\}$ is similar. Jezek [50] found that "zeunerite" (probably metazeunerite) had G. = 3.28, and was uniaxial negative with N_o = 1.585, N_e = 1.576, $N_o - N_e$ = 0.009. Color green with X = bluish, Z = emerald green. Rare.

Uranospathite [51] is a hydrated uranyl salt related to autunite and supposed to contain $12H_2O$. It is orthorhombic (pseudotetragonal) in elongated tabular crystals. Perfect 001, good 100 (and 010?) cleavages. Twinning on 110. G. = 2.50. Optic plane is 010; X = *c*. (−) 2V = 69°. N_g = 1.521, N_m = 1.510, N_p = 1.488 (calc.), $N_g - N_p$ = 0.033. Color yellow with X = pale yellow, Y and Z = deep yellow. Becomes uniaxial in a desiccator. Found in Cornwall. Very rare.

AUTUNITE ORTH. PS.–TETR. $a : b : c = 0.988 : 1 : 2.852$ $Ca(UO_2)_2P_2O_8 \cdot 8H_2O$

PHYS. CHAR.—Crystals thin basal tablets, or micaceous masses. Perfect 001 and good 100, 010 and 110 cleavages. Twinning on 110. H. = 2–2.5. G. = 3.1. F. = 3. Soluble in HNO_3.

OPT. PROP.—The optic plane is 010; X = *c*. (−) 2V = 33°, $\rho > v$, strong. N_g = 1.577, N_m = 1.575, N_p = 1.553, $N_g - N_p$ = 0.024. Stoces [48] measured N_m = 1.596 and 2E = 45° on autunite from Bohemia. Color lemon to sulphur yellow and weakly pleochroic with X = colorless, Y = Z = golden yellow.

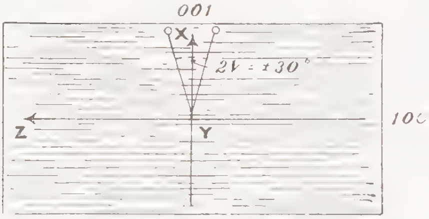

FIG. 77.—Optic orientation of autunite.

OCCUR.—With uraninite and also with silver, tin and iron ores. Rare.

DIAG. — Characterized by golden yellow color, brittle laminæ, and acute negative bisectrix normal to micaceous cleavage.

Bassetite [51] $\{Ca(UO_2)_2P_2O_8 \cdot 8(?)H_2O\}$ is monoclinic with $a : b : c = 0.347 : 1 : 0.346$, $\beta = 89° 17'$. Crystals 010 tablets with perfect 010 and good 100 and 001 cleavages. Complex lamellar twinning. G. = 3.10. Optic plane normal to 010; $Z \wedge c = -4°$. (−) 2E = 110°. N_g = 1.580, N_m = 1.574, N_p = 1.558 (calc.), $N_g - N_p$ = 0.022. Color yellow with X = pale yellow, Y and Z = deep yellow. In a desiccator the extinction angle increases to about 20°. Found in Cornwall. Very rare.

Uranospinite $\{Ca(UO_2)_2As_2O_8 \cdot 12(?)H_2O\}$ is orthorhombic (pseudotetragonal) with $a : b : c = 1 \pm : 1 : 2.914$. Crystals square basal tablets with perfect 001 cleavage. H. = 2–3. G. = 3.45. Fusible. Soluble in acid. Uniaxial negative with N_o = 1.586, N_e = 1.56, $N_o - N_e$ = 0.026 ±. Color yellow with X = nearly colorless, Z = pale yellowish. A single crystal may have this uniaxial condition as a border, and a main portion which is biaxial with X normal to the plate, Z parallel to the elongation and (−) 2V = 46°, $\rho > v$, rather strong; N_g = 1.587, N_m = 1.582, N_p = 1.560, $N_g - N_p$ = 0.027. Color yellow with X = nearly colorless, Y = Z = pale canary yellow. Found with uraninite in Saxony. Very rare.

Uranocircite $\{Ba(UO_2)_2As_2O_8 \cdot 12(?)H_2O\}$ is orthorhombic (pseudotetragonal) in basal tablets with perfect 001 and good 100 and 010 cleavages. H. = 2. G. = 3.5. F. = 3(?). Soluble in HCl. Optic plane is 010; X = *c*. (−) 2V = 10° ±. N_g = 1.623, N_m = 1.623, N_p = 1.610, $N_g - N_p$ = 0.013. Color yellow-green with X = colorless, Y = Z = pale canary yellow. Two sets of lamellar twinning at right angles visible in basal plates. Found in quartz veins. Very rare.

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[50] *Min. Abst.*, II, 1924, p. 353.

[51] A. F. Hallimond: *Mineral. Mag.*, XVII, 1915, p. 221.

Troegerite $\{(UO_2)_3As_2O_8\cdot 12H_2O\}$ is pseudotetragonal with $c = 2.16$, and perhaps monoclinic. Considered as tetragonal, crystals are 001 tablets with perfect 001 and good 010 cleavages. If monoclinic, crystals are 010 tablets. H. = soft. G. = 3.3. F. = 2.5. Soluble in acid. Negative and uniaxial with $N_o = 1.627$, $N_e = 1.582$, $N_o - N_e = 0.045$. Also slightly biaxial (negative) with X normal to plates and $N_g = 1.630$, $N_m = 1.630$, $N_p = 1.585$, $N_g - N_p = 0.045$. Color lemon yellow. Found with zeunerite, etc. Very rare.

Phosphuranylite $\{(UO_2)_3P_2O_8\cdot 6(?)H_2O\}$ is pseudotetragonal and probably monoclinic. Crystals 010 tablets. F. = 3?. Soluble in HCl. $X = b$. (−) 2V = nearly 0°, very strong dispersion. $N_g = 1.720$, $N_m = 1.720$, $N_p = 1.691$, $N_g - N_p = 0.029$. Color deep lemon yellow with X = nearly colorless, Y and Z = canary yellow. Found in mines in North Carolina. Very rare.

Tyuyamunite $\{Ca(UO_2)_2V_2O_8\cdot 4 \pm H_2O?\}$ is orthorhombic in 001 plates. Perfect 001 and imperfect 010 and 100 cleavages. H. = soft. G. = 3.7–4.3, varying with water content. $X = c$; $Y = b$. (−) 2V = 36°–55°, $\rho < v$ rather strong. $N_g = 1.895$, $N_m = 1.870$, $N_p = 1.670$, $N_g - N_p = 0.235$. Another measure[52] gave $N_g = 1.965–1.968$, $N_m = 1.927–1.932$, $N_p =$ (calc.) 1.75–1.80, $N_g - N_m = 0.044$. Another crystal gave $N_g = 1.92$, $N_m = 1.895$, $N_p =$ (calc.) 1.78, $N_g - N_p = 0.14$. Little changed by heat. Color yellow with X = nearly colorless, Y = canary yellow, Z = darker canary yellow. In potassium mercuric iodide the Ca is slowly replaced by K_2 with decrease of H_2O. Found in Russia. Very rare.

Sincosite[53] $\{Ca(VO)_2P_2O_8\cdot 5H_2O?\}$ is tetragonal in rectangular basal plates with distinct 001 cleavage. H. = low. G. = 2.84. Soluble in dilute acid. Uniaxial negative with $N_o = 1.680$, $N_e = 1.655$, $N_o - N_e = 0.025$. Also biaxial (altered?) with (−) 2E = 0°–80°, $\rho > v$, strong, $N_g = 1.693$, $N_m = 1.690$, $N_p = 1.675$, $N_g - N_p = 0.018$, Color emerald green to brass yellow with X = colorless to pale yellow, Z = gray-green. Found in shale in Peru. Very rare.

Carnotite $\{K_2(UO_2)_2V_2O_8\cdot 4 \pm H_2O?\}$ is orthorhombic in 001 plates of angles of 78° and 102°, with perfect 001 cleavage. H. = soft. $X = c$; $Y = a$. (−) 2V = 39°–50°, $\rho < v$, weak. $N_g = 1.950$, $N_m = 1.925$, $N_p = 1.750$, $N_g - N_p = 0.200$. Another measure gave: $N_g = 1.92$, $N_m = 1.895$, $N_p = ?$; $N_g = 2.08$, $N_m = ?$, $N_p = 2.06$, $N_g - N_p = 0.02$ (Hess and Foshag[54]). Color yellow. Colorless in section or slightly colored and pleochroic. Found in sandstone in Colorado, etc. Very rare.

Dewindtite[55] $(3PbO\cdot 5UO_3\cdot 2P_2O_5\cdot 12H_2O?)$ is orthorhombic; crystals minute 100 plates with 100 cleavage. G. = 4.08. Soluble in HNO_3. Optic plane is 001; $X = a$. (+) 2V = large, $\rho < v$. $N_g = ?$, $N_m = 1.763 \pm$, $N_p = 1.762 \pm$, but $N_m - N_p = 0.004 \pm$. Color canary yellow; not pleochroic. Found with torbernite in the Congo. Very rare.

Uvanite $(2UO_3\cdot 3V_2O_5\cdot 15H_2O)$ is orthorhombic with two pinacoidal cleavages. Soluble in ammonium carbonate solution. (+) 2V = 52°; $N_g = 2.057$, $N_m = 1.879$, $N_p = 1\ 817$, $N_g - N_p = 0.24$. Color brownish yellow with X = light brown to yellow, Y = dark brown, Z = greenish yellow. Found in rocks in Utah. Very rare.

Parsonsite[56] $(2PbO\cdot UO_3\cdot P_2O_5\cdot H_2O?)$ is monoclinic (?) with $\beta = 81°$. G. = 6.23. Fuses to black globule. Soluble in acid. Extinction at 12° from c in 010; elongation parallel to c is positive. Biaxial. $N > 1.99$, $N_g - N_p$ = weak. Color brown to colorless, the color due to inclusions. Found in ore deposits in the Congo. Very rare.

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[52] H. E. Merwin: *Am. Jour. Sci.*, CCVIII, 1924, p. 208. C. S. Ross (*U. S. Geol. Surv. Bull.* 750, 1924, p. 73) gives: 2V = 48°, $N_g = 1.953$, $N_m = 1.868$, $N_p = 1.72$, but notes that N_g and N_m are of doubtful accuracy because in melts of S and Se the mineral loses water.

[53] W. T. Schaller: *Am. Jour. Sci.*, CCVIII, 1924, p. 462.

[54] *Am. Mineral.*, XI, 1926, p. 66.

[55] A. Schoep: *Comp. Rend.*, CLXXIV, 1922, p. 623; *Bull. Soc. Fr. Min.*, XLVIII, 1925, p. 77.

[56] A. Schoep: *Comp. Rend.*, CLXXVI, 1923, p. 171.

Fernandinite ($CaO \cdot V_2O_4 \cdot 5V_2O_5 \cdot 14H_2O$) is fibrous, rarely in rectangular plates, soluble in acid to green solution, $N_m = 2.05$, $N_g - N_p$ = strong. Color dull green, not pleochroic. Found in Peru. Very rare.

Walpurgite ($3UO_3 \cdot 5Bi_2O_3 \cdot 2As_2O_5 \cdot 12H_2O$) is triclinic with $a : b : c = 0.686 : 1 : ?$, $\alpha = 70° \; 44'$, $\beta = 114° \; 8'$, $\gamma = 85° \; 30'$. Crystals 010 tablets vertically elongated. Twinned on 010. H. = 3.5. G. = 5.8. F. = 1.5. X nearly normal to 010. Maximum extinction is at 8° to c in zone normal to 010. In 010 Y to c = 12°. $(-) \; 2V = 52° \pm$. $N_g = 2.05$, $N_m = 2.00$, $N_p = 1.90$, $N_g - N_p = 0.15$. Other measures give: $N_g = 2.005$ and 2.03, $N_m = 1.975$ and 2.01, $N_p = 1.871$, $N_g - N_p = 0.134$. Color wax yellow. Found in ore deposits in Bohemia and Saxony. Very rare.

11. ANHYDROUS PHOSPHATES, ETC., OF DIVALENT AND MONOVALENT BASES

Merrillite [57] ($Na_2O \cdot 3CaO \cdot P_2O_5$) is hexagonal with hexagonal prismatic cleavage. G. = 3.10. Soluble in HNO_3. Uniaxial negative with $N_o = 1.623$, $N_e = 1.620$, $N_o - N_e = 0.003$. Extinction often undulatory; also reported as biaxial positive(?). Colorless. Found only in meteorites. Rare.

Beryllonite ($NaBePO_4$) is orthorhombic; $a : b : c = 0.572 : 1 : 0.549$; crystals short macrodomatic or basal tablets. Twinning on 110 to pseudohexagonal forms. Perfect 001, good 100, and poor 010 cleavages. H. = 6. G. = 2.85. F. = 5. Soluble in acid. The optic plane is 100; X = c. $(-) \; 2V = 67° \; 34'$; $2E = 121° \; 1'$, $\rho < v$, weak. $N_g = 1.562$ Na, $N_m = 1.558$, $N_p = 1.552$, $N_g - N_p = 0.010$. Colorless to yellowish. Cavities, with or without liquid inclusions, are common; they may be arranged parallel to the vertical axis. Found in pegmatite in Maine. Rare.

TRIPHYLITE-LITHIOPHILITE ORTHORHOMBIC $LiFePO_4$–$LiMnPO_4$

PHYS. CHAR.—Crystals prismatic with perfect 001 and good 010 and 110 cleavages. H. = 5. G. = 3.45–3.55. F. = 1.5–2. Soluble in HCl.

OPT. PROP.—The optic properties of the series vary with the variations in tenor of iron and manganese, as follows: [58]

Color	% FeO	% $LiFePO_4$	N_g	N_m	N_p	$N_g - N_p$	2V over b	Orientation
Light gray	35.05	77.0	....	1.702 Na	....	....	(−) 120°	X = c, Y = a
	30.9	....	1.702	1.695	1.694	0.008	(+) 62°	
Light blue	26.58	58.5	1.691 Li	1.684 Li	1.683 Li	0.008 Li	(+) 15° 3′ Li	X = c, Y = a
			1.692 Na	1.688 Na	1.688 Na	0.004 Na	(+) 0° 0′ Na	Z = b
			1.698 Tl	1.692 Tl	1.691 Tl	0.007 Tl	(+) 21° 53′ Tl	X = a, Y = c
Light clove brown	13.63	30.0	....	1.682 Na	....	....	(+) 56° 4′ Na	X = a, Y = c
	12.57	20.7	1.684	1.677	1.674	0.010		
	9.42	....	1.687 Na	1.679 Na	1.676 Na	0.011 Na	(+) 62° 54′ Na	
Salmon	4.24	9.3	....	1.675 Na	....	....	(+) 65° 13′ Na	X = a, Y = c
	2.94	....	1.673	1.666	1.663	0.010		

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[57] E. V. Shannon and E. S. Larsen: *Am. Jour. Sci.*, CCIX, 1925, p. 250.

[58] S. L. Penfield and J. H. Pratt: *Am. Jour. Sci.*, CL, 1895, p. 387; see also: E. Mäkinen: *Bull. Geol. Com. Finlande*, 35, 1913, p. 96, and K. K. Landes: *Am. Mineral.*, X, 1925, p. 355.

The variations in indices and optic angle in sodium light are shown in graphic form in Fig. 78, which shows that the optic plane is probably 010 in pure iron triphylite, and that the index in the direction of *a* changes from the least to the greatest, passing through a uniaxial condition twice.

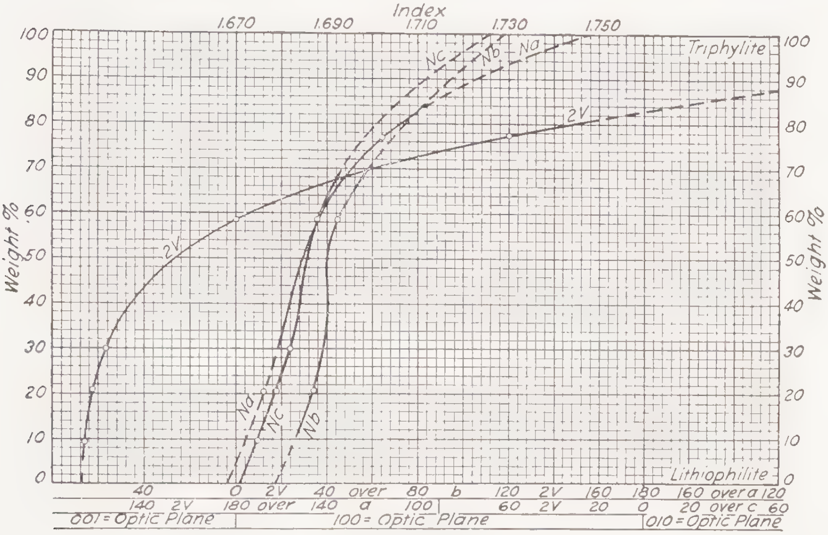

FIG. 78.—Variations in composition and optic properties in the triphylite-lithiophilite series.

Color greenish gray or bluish in triphylite, salmon pink, yellow or brown in lithiophilite; often black on the surface. Lithiophilite is pleochroic with X = deep pink, Y = pale greenish yellow, Z = pale pink.

ALTER.—Oxidizes and hydrates very readily to heterosite, hureaulite, dufrenite, etc., turning brown, red, or black, and developing three good cleavages. Ultimately pyrolusite and limonite may form.

Natrophilite ($NaMnPO_4$) is orthorhombic with $a : b : c = 0.472 : 1 : 0.55 \pm$. Perfect 001 and good 010 cleavages. H. = 4.5–5. G. = 3.4. F. = 2–2.5. Soluble in acid. Optic plane is 001; Z = *b*. (+) 2V = 72°, $\rho < v$, strong. $N_g = 1.684$, $N_m = 1.674$, $N_p = 1.671$, $N_g - N_p = 0.013$. Color deep wine yellow. Found in pegmatite. Very rare.

12. HYDROUS PHOSPHATES, ETC., OF DIVALENT AND MONOVALENT BASES

Freirinite [59] ($6Na_2O \cdot 3CaO \cdot 9CuO \cdot 4As_2O_5 \cdot 12H_2O$?) is probably tetragonal with perfect 001 and indistinct 110 cleavages. G > 3.32. F. = easy. Soluble in HCl. Uniaxial negative with $N_o = 1.748$, $N_e = 1.645$, $N_o - N_e = 0.103$. Color greenish blue with X < Z. Found in cobalt deposits. Rare.

Struvite ($NH_4MgPO_4 \cdot 6H_2O$) is orthorhombic with $a : b : c = 0.567 : 1 : 0.912$. Crystals hemimorphic, prismatic, etc. Twinning on 001. Perfect 001 and good 010 cleavages. H. = 2. G. = 1.72. F. = 3. Soluble in acids. Optic plane is 100; Z = b. (+) 2V = 37°, $\rho < v$ strong. $N_g = 1.504$, $N_m = 1.496$, $N_p = 1.495$, $N_g - N_p = 0.009$. Colorless or yellow. Found in guano. Rare.

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[59] W. F. Foshag: *Am. Mineral.*, IX, 1924, p. 30.

Hannayite $\{H_4(NH_4)_2MgP_2O_8 \cdot 8H_2O\}$ is triclinic with $a : b : c = 0.699 : 1 : 0.975$, $\alpha = 122° \ 31'$, $\beta = 126° \ 46'$, $\gamma = 54° \ 9'$. Crystals prismatic or platy with cleavage parallel to 001, 110, $1\bar{1}1$ and 130. H. = soft. G. = 1.89. Optically it seems to be monoclinic (Larsen) with X = b (normal to perfect 010 cleavage) and $Y \wedge c$ (elongation) = 33°. (−) 2V = 42°, dispersion weak. $N_g = 1.575$, $N_m = 1.572$, $N_p = 1.555$, $N_g - N_p = 0.020$. Color yellowish. Found in bat guano. Very rare.

13. PHOSPHATES, ETC., OF TRIVALENT AND MONOVALENT BASES

Soumansite (phosphate of Al and Na with OH, F) is tetragonal with $c = 0.767$. Crystals pyramidal. H. = 4.5. G. = 2.87. F. = difficult. Difficultly soluble in acid. Uniaxial positive with N = 1.555 ±, $N_g - N_p$ = distinct. Basal sections may be divided into vague segments, each biaxial with (+) 2E = 70° (maximum). Colorless. Soumansite is related to and associated with morinite. Found in a tin deposit in France. Very rare.

Swedenborgite [60] $\{Na(AlO)_2SbO_4\}$ is hexagonal with $c = 1.631$. Crystals short prismatic with distinct 0001 cleavage. H. = 8. G. = 4.29. Insoluble. Uniaxial negative with $N_o = 1.7724$ Na, $N_e = 1.7700$, $N_o - N_e = 0.0024$. Colorless to yellow. Found in ore deposits. Very rare.

Durangite ($NaAlFAsO_4$) is monoclinic with $a : b : c = 0.772 : 1 : 0.822$, $\beta = 64° \ 47'$. Crystals pyramidal with distinct 110 cleavages at 69° 50′. H. = 5. G. = 3.94–4.07. F. = 2. Decomposed by H_2SO_4. Optic plane is normal to 010; $X \wedge c = -25°$, distinct dispersion. (−) 2V = 57°, $\rho < v$, weak. $N_g = 1.685$, $N_m = 1.673$, $N_p = 1.634$, $N_g - N_p = 0.051$. Color orange-red with X = orange-yellow, Y = pale orange yellow, Z = nearly colorless. Found in a tin mine in Mexico. Very rare.

Amblygonite - Montebrasite series [61] ($LiAlFPO_4 \cdot \frac{1}{4}H_2O$–$LiAlOHPO_4 \cdot \frac{1}{4}H_2O$) is triclinic with $a : b : c = 0.733 : 1 : 0 : 763$, $\alpha = 108° \ 31'$, $\beta = 97° \ 48'$, $\gamma = 106° \ 27'$. Multiple lamellar twinning on $\bar{1}01$ and on 101; perfect 001, good 100 and rare $0\bar{2}1$ cleavages. H. = 6. G. = 2.98–3.15. F. = 2. Soluble in H_2SO_4. In a sample with only 12.6 per cent of the hydroxyl molecule the optic plane makes an angle of 12° with $1\bar{1}0$ and 76° with 001 in the acute angle $1\bar{1}0 : 001$; X lies in $1\bar{1}0$ and makes an angle of 17° with the edge $001 : 1\bar{1}0$. (−) 2V = 50° ±, $\rho > v$ weak, with strong crossed and distinct inclined dispersion. $N_g = 1.598$, $N_m = 1.593$, $N_p = 1.578$, $N_g - N_p = 0.020$. Color greenish, violet, pink, white. With increase in hydroxyl the optic angle about X increases (passes 90° at about 60 per cent OH), the density decreases, the refringence increases considerably and birefringence increases a little, as shown approximately in Fig. 78*a*. With about 85 per cent OH molecule: $(+)2V = 80° \pm$, $\rho < v$ with horizontal and weak inclined dispersion. $N_g = 1.630$, $N_m = 1.614$, $N_p = 1.607$, $N_g - N_p = 0.023$. Color white. Found in pegmatite.

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[60] G. Aminoff: *Zeit. Kryst.*, LX, 1924, p. 262.

[61] A. N. Winchell: *Am. Mineral.*, XI, 1926, p. 246.

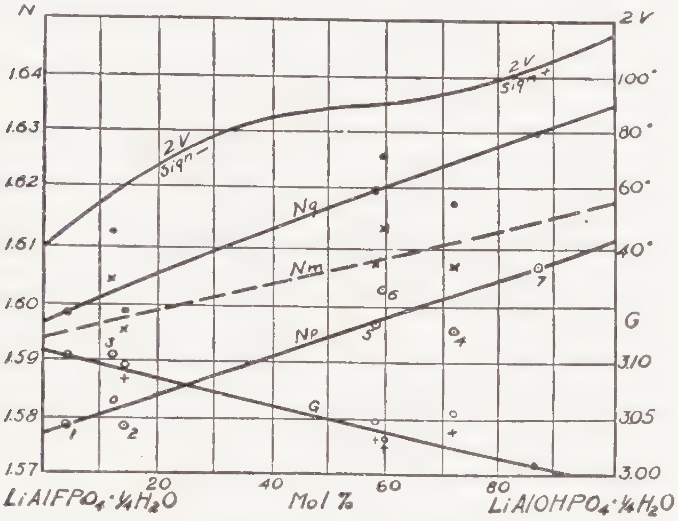

FIG. 78*a*.—Variations in composition and optic properties in the amblygonite-montebrasite series.

Fremontite[61] $\{NaAl(OH,F)PO_4 \cdot \frac{1}{4}H_2O\}$ is triclinic (?) and isomorphous with amblygonite. Two directions of lamellar twinning. Perfect 001, good 100 and one other cleavage. X nearly normal to 001; in a cleavage piece $Z' \wedge$ twinning $= 29°$. $(+)$ 2V = very large. $N_g = 1.615$, $N_m = 1.603$, $N_p = 1.594$, $N_g - N_p = 0.021$. Another measure gave $N_m = 1.618$ and 2V = nearly 90°. Color gray to white. Found in pegmatite.

14. ANHYDROUS PHOSPHATES, ETC., OF TRIVALENT AND DIVALENT BASES

Arseniosiderite $\{Ca_3Fe_4(OH)_9As_3O_{12}\}$ is tetragonal (?) with basal cleavage. H. = 1–2. G. = 3.5–3.9. F. = 3. Soluble in acid. Uniaxial negative with $N_o = 1.870$, $N_e = 1.792$, $N_o - N_e = 0.078$. Some crystals slightly biaxial. Color yellow or brown with X = clear yellow, Z = reddish brown. Found in manganese ore in France. Very rare.

HAMLINITE GROUP

The minerals of the hamlinite group are trigonal basic phosphates of aluminum with strontium, lead or barium. Florencite is related, and the whole series is closely related to the alunite and beudantite groups. The minerals here included are:

Goyazite	$\{Al(OH)_2\}_6\ Sr(HPO_4)_2Sr(PO_4)_2$	$c = 1.135$
Gorceixite	$\{Al(OH)_2\}_6\ Ba(HPO_4)_2Ba(PO_4)_2$	
Plumbogummite	$\{Al(OH)_2\}_6\ Pb(HPO_4)_2Pb(PO_4)_2$	

Goyazite ($2SrO \cdot 3Al_2O_3 \cdot 2P_2O_5 \cdot 7H_2O$) is trigonal with $c = 1.135$. Granular or tabular with perfect basal cleavage. H. = 5. G. = 3.2. F. = 4. Insoluble in acids. Uniaxial positive with $N_o = 1.6294$ Na, $N_e = 1.6387$, $N_e - N_o = 0.0093$ (Brazil—Jezek [62]); $N_o = 1.620$, $N_e = 1.630$, $N_e - N_o = 0.010$ (Colorado—Larsen). Also biaxial with 2E = 50° (maximum) in hexagonal segments, the optic plane being normal (or nearly so) to hexagonal prism faces in each segment. $Y \wedge$ hexagonal edge = 0° to 5°. Some crystals show zonal growths. Colorless to reddish brown with X = reddish brown and Z = yellow in thick plates. Found in pegmatite. Very rare.

Gorceixite ($2BaO \cdot 3Al_2O_3 \cdot 2P_2O_5 \cdot 7H_2O$) is microcrystalline in pebbles. H. = 6. G. = 3.1. Uniaxial positive with $N_o = 1.6253$, $N_e - N_o$ = weak. Color brown or white. Found in diamond sands of Brazil. Very rare.

Plumbogummite ($2PbO \cdot 3Al_2O_3 \cdot 2P_2O_5 \cdot 7H_2O$) is gumlike. H. = 4–5. G. = 4.0–4.9. F. = 2(?). Soluble in HNO_3. Uniaxial positive with $N_o = 1.653$, $N_e = 1.675$, $N_e - N_o = 0.022$. Indices vary about ± 0.01. Color yellow or brown; weakly pleochroic in yellow with $X < Z$. Found in slate with galena, etc. Very rare.

Hematolite $\{Mn_4(OH)_8(Al,Mn)AsO_4\}$ is trigonal with $c = 0.889$. Crystals rhombohedral with perfect 0001 cleavage. H. = 3.5. G. = 3.4. F. = 7. Soluble in acid. Uniaxial negative with $N_o = 1.733$, $N_e = 1.714$, $N_o - N_e = 0.019$. Also biaxial with 2V small. Color brownish red to black; yellowish to brown and not pleochroic in section. Found in a mine in Sweden. Very rare.

Dussertite [63] $\{Ca_3Fe_3(OH)_9As_2O_8\}$ is hexagonal in basal plates. H. = 3.5. G. = 3.75. Soluble in dilute HCl. Uniaxial negative with N_o and N_e between 1.80 and 1.88, $N_o - N_e = 0.012$. Yellowish green in section with $O > E$ weak. Found in sediments in Algeria.

Crandallite [64] ($CaO \cdot 2Al_2O_3 \cdot P_2O_5 \cdot 5H_2O$?) is fibrous. H. = 4. Fuses with decrepitation. Uniaxial negative with $N_o = 1.595$, $N_e = 1.585$, $N_o - N_e = 0.010$. Color white. Apparently an alteration product of goyazite. Found in a quartz vein in Utah. Very rare.

Arseniopleite $\{9(Mn,Ca,Pb,Mg)O \cdot (Mn,Fe)_2O_3 \cdot 3As_2O_5 \cdot 3H_2O\}$ is trigonal with rhombohedral cleavage. H. = 3.5. F. = easy to black bead. Soluble in HCl. Uniaxial positive with $N_o = 1.794$, $N_e = 1.803$, $N_e - N_o = 0.009$. Some crystals biaxial with small optic angle. Color brownish red; blood red and not pleochroic in section. Found in ore deposits in Sweden. Very rare.

Tavistockite $\{Ca_3Al_2(OH)_6P_2O_8\}$ is orthorhombic in vertical needles with perfect 100 cleavage. F. = 7. Soluble in acid. Optic plane is 100; $Z = c$. (+) 2V = 74°±. $N_g = 1.544$, $N_m = 1.530$, $N_p = 1.522$, $N_g - N_p = 0.022$. Color white. Found on quartz. Very rare.

Flinkite $\{Mn_2(OH)_4MnAsO_4\}$ is orthorhombic with $a : b : c = 0.413 : 1 : 0.739$. Crystals 001 tablets. No good cleavage. H. = 4–4.5. G. = 3.87. F. = easy. Soluble in acid. Optic plane is 001; $Z = a$. (+) 2V = large, with slight dispersion. $N_g = 1.834$, $N_m = 1.801$, $N_p = 1.783$, $N_g - N_p = 0.051$. Color greenish brown with X = yellowish or brownish green, Y = yellowish green, Z = orange-brown. Found in a mine in Sweden. Very rare.

Retzianite (arsenate of Y, Mn, Ca, H, etc.) is orthorhombic with $a : b : c = 0.441 : 1 : 0.727$. Crystals prisms or 010 tablets without cleavage. H. = 4. G. = 4.15, F. = 7. Soluble in acids. Optic plane is 010; $Z = a$. (+) 2V = large, $\rho < v$ weak. $N_g = 1.800$, $N_m = 1.788$, $N_p = 1.777$, $N_g - N_p = 0.023$. Color dark chocolate to chestnut brown with X = colorless, Y = pale yellowish brown, Z = reddish brown. Found in a manganese mine in Sweden. Very rare.

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[62] *Bull. Intern. Acad. Sci. Bohême*, XIII, No. 2, 1908.

[63] J. Barthoux: *Comp. Rend.*, CLXXX, 1925, p. 299.

[64] G. F. Loughlin and W. T. Schaller: *Am. Jour. Sci.*, CXCIII, 1917, p. 69.

Carminite $\{Pb_3Fe_{10}(AsO_4)_{12}?\}$ is orthorhombic and acicular with prismatic cleavage. H. = 2.5–3. G. = 4.1. F. = easy. Soluble in HNO_3. Described as optically positive, but no interference figure was obtained; the needles probably have positive elongation and doubtful optic sign. N = 1.83 (est.), $N_g - N_p$ = strong. Color carmine red to reddish brown. Found in ore deposits. Very rare.

Lazulite $\{(Fe,Mg)Al_2(OH)_2P_2O_8\}$ is monoclinic with $a : b : c = 0.975 : 1 : 1.694$, $\beta = 88° 2'$; crystals acute pyramids; twinning on 100; indistinct 110 cleavage. H. = 5–6. G. = 3.1. F. = 7. Insoluble in HCl. The optic plane is 010; $X \wedge c = -9°$ to $-10°$. $(-)$ $2V = 69° \pm$, $2E = 132°–136°$, $\rho < v$ weak. $N_g = 1.639$, $N_m = 1.632$, $N_p = 1.603$, $N_g - N_p = 0.036$. (A variety[65] with about 3 per cent CaO has: G. = 2.96, $N_g = 1.642$, $N_m = 1.633$, $N_p = 1.604$, $N_g - N_p = 0.038$.) Color azure to Prussian blue with X = colorless, Y and Z = azure blue. Inclusions with movable bubbles may be very abundant. Found in veins in quartzite, etc. Rare. Distinguished from lazurite, blue tourmaline and blue corundum by its pleochroism and biaxial character; from blue cordierite, sapphirite and dumortierite by its strong birefringence, and from blue cyanite and blue amphibole by the absence of cleavage.

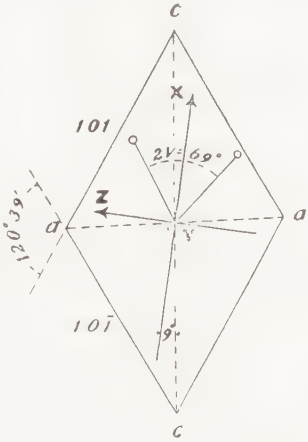

Fig. 79.—Optic orientation of lazulite.

Synadelphite $\{Mn_5(OH)_{10}(Al,Mn)_2As_2O_8\}$ is monoclinic with $a : b : c = 0.858 : 1 : 0.919$, $\beta = 90° \pm$. Crystals prismatic or pyramidal without distinct cleavage. H. = 4.5. G. = 3.5. F. = easy. Soluble in HCl. Optic plane normal to 010; $X \wedge c = 45°$. $(+)$ 2V = small. $N_g = 1.90$, $N_m = 1.87$, $N_p = 1.86$, $N_g - N_p = 0.04$. Color dark brownish to black; nearly opaque dark brown in section with slight pleochroism. Found in a mine in Sweden. Very rare.

Manganostibite $\{10MnO \cdot (Sb,As)_2O_5\}$ is monoclinic in fibers. Perfect 010 cleavage. F. = 7. Soluble in HCl. Optic plane normal to 010 cleavage; positive elongation and large extinction angle in 010. $(-)$ 2V = small. $N_g = 1.96$, $N_m = 1.95$, $N_p = 1.92$, $N_g - N_p = 0.04$. Color black with X = reddish brown, Y and Z = nearly opaque. Found in a mine in Sweden. Very rare.

ALLACTITE Mono. $a : b : c$[66] $= 0.821 : 1 : 0.451$ $\beta = 84° 23'$ $4Mn(OH)_2 \cdot Mn_3As_2O_8$

Phys. Char.—Crystals prismatic or 100 tablets. Distinct $\bar{1}01$, fair 010 and poor 100 cleavages. H. = 4.5. G. = 3.84. F. = 6. Soluble in acid.

Opt. Prop.—The optic plane is normal to 010 for red and yellow and parallel to 010 for blue. $X \wedge c = -49°$ (to $-51°$) for all colors. $(-)$ $2V = 8°$ 56′ B, 4° 0′ D, 0° (573 $\mu\mu$), 8° 23′ E, 11° 22′ F. $N_g = 1.779$ Na (Aminoff[66]), $N_g = 1.787$, $N_m = 1.786$, $N_p = 1.761$, $N_g - N_p = 0.026$ (Larsen).

Color brownish red with X = pale sea green, Y and Z = yellowish green to pale yellow.

Occur.—In ore deposits in Sweden, etc. Rare.

Griphite (phosphate of Mn, H, Fe, Al, Ca, etc.) is apparently amorphous with H. = 5.5. G. = 3.4. F. = easy. Soluble in HCl. Isotropic with N = 1.64 ±. Color brown. Found in tin deposit in South Dakota. Very rare.

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[65] T. L. Watson: *Jour. Wash. Acad. Sci.*, XI, 1921, p. 386.

[66] G. Aminoff: *Geol. För. Förh. Stockholm*, XLIII, 1921, p. 24.

Sarcopsite $\{(Fe,Mn,Ca)_7F_2(PO_4)_4\}$ is probably monoclinic[67]; it is fibrous with distinct cleavage nearly normal to the fibers and indistinct cleavage parallel thereto. If the elongation is vertical, the distinct cleavage may be 001 and the indistinct cleavage may be 010. Then the extinction in 010 is at 45°; (extinction of 6° or 7° reported in fragments nearly normal to 001 and 010 suggests triclinic symmetry). H. = 4. G. = 3.64. Soluble in acid. $N_m = 1.725$, $N_g - N_p =$ very weak. Color flesh-red to lavender, altering to blue green or brown; streak light yellow. Found in pegmatite. Very rare.

15. HYDROUS PHOSPHATES, ETC., OF TRIVALENT AND DIVALENT BASES

Pseudowavellite[41] (hydrous phosphate of Al and Ca) is trigonal with perfect basal cleavage. Uniaxial positive with $N = 1.63 \pm$, $N_o - N_e = 0.015$. Colorless needles. Found on limonite or wavellite; very rare.

Childrenite $\{(Fe,Mn)Al(OH)_2PO_4 \cdot H_2O\}$ is orthorhombic with $a : b : c = 0.778 : 1 : 0.526$; crystals pyramidal or prismatic with imperfect 100 cleavage. H. = 4.5–5. G. = 3.18–3.24. F. = 4, after swelling. Soluble in HCl. The optic plane is 100; $X = b$. $(-)\ 2V = 45°$, $\rho > v$, strong. $N_g = 1.684$, $N_m = 1.678$, $N_p = 1.643$, $N_g - N_p = 0.041$. Color white to brownish. Found in slate quarries and pegmatites. Rare.

Eosphorite $\{(Mn,Fe)Al(OH)_2PO_4 \cdot H_2O)\}$ is orthorhombic with $a : b : c$[68] $= 0.772 : 1 : 0.513$. Crystals prismatic, vertically striated. Good 100 cleavage. H. = 5. G. = 3.1–3.15. F. = 4. Soluble in HCl. Optic plane is 100; $X = b$. $(-)\ 2V = 40 \pm$, $\rho < v$ strong. $N_g = 1.664, 1.662$; $N_m = 1.660, 1.656$; $N_p = 1.633, 1.631$; $N_g - N_p = 0.031$ (Larsen); $N_g = 1.669$; $N_m = ?$;.$N_p = 1.642$; $N_g - N_p = 0.027$ (with FeO = 5.55—Drugman[68]); $N_g = 1.658$; $N_m = 1.650$; $N_p = 1.629$ (with FeO = 1.38—Landes[10]). Color rose-pink, yellowish or bluish, and weakly pleochroic with X = yellowish, Y = deep pink, Z = nearly colorless. Found in pegmatites. Rare.

Salmonsite $(9MnO \cdot Fe_2O_3 \cdot 4P_2O_5 \cdot 14H_2O?)$ is orthorhombic with two distinct cleavages at right angles. H. = 4. G. = 2.88. Z parallel to fibers. $(+)\ 2V =$ very large, $\rho < v$ strong. $N_g = 1.670$, $N_m = 1.66$, $N_p = 1.655$, $N_g - N_p = 0.015$. Color buff with X = colorless, Y = yellow, Z = orange-yellow. Found in ore deposits. Rare.

Mazapilite $\{Ca_3Fe_4(OH)_6(AsO_4)_4 \cdot 3H_2O\}$ is orthorhombic with $a : b : c = 0.862 : 1 : 0.997$. Crystals prismatic. H. = 4.5. G. = 3.57. F. = easy. Soluble in acid. Sensibly uniaxial and negative with $N_o = 1.898$, $N_e = 1.815$, $N_o - N_e = 0.083$. Color black; blood red in section with X = nearly colorless, Z = dark reddish brown. Probably the same as *arseniosiderite*, according to Larsen.[69] Found in an ore deposit in Mexico. Very rare.

Mixite $(20CuO \cdot Bi_2O_3 \cdot 5As_2O_5 \cdot 22H_2O)$ is orthorhombic in acicular crystals. H. = 3–4. G. = 3.79. F. = 2. Coated white in HNO_3. $Z = c$. $(+)\ 2V =$ very small to 0°. $N_g = 1.830$ (1.810), $N_m = 1.745$, $N_p = 1.745$ (1.730), $N_g - N_p = 0.085$. Color emerald green; in section pale green, not pleochroic. Found in copper deposits in Utah. Very rare.

Churchite $\{Ca_3Ce_{10}(PO_4)_{12} \cdot 24H_2O?\}$ is orthorhombic (?); crystals rectangular tablets with bevels on long edges and one perfect cleavage. H. = 3–3.5. G. = 3.14. F. = 7. Soluble in acid. Axis Z normal to plates. $(+)\ 2V = 0°$ perceptibly, $N_g = 1.654$, $N_m = N_p = 1.620$, $N_g - N_p = 0.034$. Colorless. Found in copper ore. Very rare.

[67] E. F. Holden: *Am. Mineral.*, V, 1920, p. 99; ix, 1924, p. 205, according to the new formula this mineral belongs after triploidite on page 133.

[68] J. Drugman: *Mineral. Mag.* XVII, 1914, p. 199.

[69] *Am. Mineral.*, III, 1918, p. 12.

Calcioferrite ($6CaO \cdot 3Fe_2O_3 \cdot 4P_2O_5 \cdot 19H_2O$?) is monoclinic (?) in scaly nodules with very perfect 001 cleavage. H. = 2.5. G. = 2.53. F. = easy. Decomposed by HCl. Sensibly uniaxial negative with $N_o = 1.56–1.58$, $N_o - N_e$ = weak. Color yellow to green Found in clay in Bavaria. Very rare.

Chenevixite ($2CuO \cdot Fe_2O_3 \cdot As_2O_5 \cdot 2H_2O$) is cryptocrystalline. H. = 4. G. = 3.9. F. = 2.5. Optic sign unknown. N = 1.88, $N_g - N_p$ = rather strong. Color dark green to greenish yellow. Found in copper ores in Utah, etc. Very rare.

Roscherite $\{Ca(Mn,Fe)AlOHP_2O_8 \cdot 2H_2O\}$ is monoclinic with $a : b : c = 0.94 : 1 : 0.88$, $\beta = 89° 10'$. Crystals tabular with perfect 001 and fair 010 cleavages. H. = 4.5. G. = 2.92. Optic plane and X normal to 010; $Y \wedge c = -15°$ with crossed dispersion. (−) 2V = large, $\rho > v$, very strong. $N_m = 1.625$, $N_g - N_p$ = rather strong. Color brown with X = yellow to olive green, Y = yellowish brown, Z = chestnut brown. Found in pegmatite in Bavaria. Very rare.

Liroconite $\{Cu_2Al(OH)_4AsO_4 \cdot 5H_2O?\}$ is monoclinic with $a : b : c = 1.319 : 1 : 1.681$, $\beta = 88° 33'$. Crystals have 011 and 110 faces with indistinct 110 and 011 cleavages. H. = 2–2.5. G. = 2.9. F. = 3–3.5. Soluble in HNO_3. Optic plane normal to 010; $Z \wedge c = -25°$. (−) 2V = 67°, $\rho < v$, moderate. $N_g = 1.675$, $N_m = 1.652$, $N_p = 1.612$, $N_g - N_p = 0.063$. Color sky blue to green; in section greenish and not pleochroic. Found in copper deposits. Rare.

Chalcosiderite ($CuO \cdot 3Fe_2O_3 \cdot 2P_2O_5 \cdot 9H_2O$?) is triclinic with $a : b : c = 0.791 : 1 : 0.605$, $\alpha = 92° 58'$, $\beta = 93° 30'$, $\gamma = 107° 49'$. Crystals in sheaf-like groups with good 010 cleavage. H. = 4.5. G. = 3.1. F. = 4–4.5. Soluble in HCl. Acute bisectrix X nearly = b, with very strong crossed dispersion. (−) 2V = 24°, $\rho > v$, very strong. $N_g = 1.845$, $N_m = 1.840$, $N_p = 1.773$, $N_g - N_p = 0.072$. Color siskin-green with X = colorless, Z = pale green in thick sections. Plates parallel to 010 give no extinction in white light, but very abnormal red, blue and green interference colors, changing on rotation. Found in copper deposits. Very rare.

Turquois ($CuO \cdot 3Al_2O_3 \cdot 2P_2O_5 \cdot 9H_2O$) is isomorphous with chalcosiderite. Crystals prismatic, very rare, with distinct $1\bar{1}0$ and one other cleavage. H. = 5. G. = 2.84. F. = 7, but turns brown. Soluble in acid only after ignition. Extinction on $1\bar{1}0$ is 12° to c and 12° to ($0\bar{1}1$?). Extinction on the other cleavage is at 5° and 34°. (+) 2V = 40°, $\rho < v$, strong. $N_g = 1.65$, $N_m = 1.62$, $N_p = 1.61$, $N_g - N_p = 0.04$. Color sky blue to bluish green and pleochroic from colorless to pale bluish. Found in veins in trachyte in Persia, etc. Rare.

Vauxite[70] ($FeO \cdot Al_2O_3 \cdot P_2O_5 \cdot 6H_2O$?) is described as triclinic with $a : b : c = 1.15 : 1 : 1.262$, $\alpha = 99° 32'$, $\beta = 102° 14'$, $\gamma = 110° 14'$. Crystals 010 tablets without known cleavage. H. = 3.5. G. = 2.37. Soluble in HCl. Axis Z about normal to 010 in which $X' \wedge c = -27°$. (+) 2E = 32°, $\rho > v$. $N_g = 1.562$, $N_m = 1.555$, $N_p = 1.551$, $N_g - N_p = 0.011$. Color sky blue to Venetian blue with a white streak. Strongly pleochroic with X′ and Z′ = colorless and Y′ = blue. Found in ore deposits in Bolivia. Very rare.

Paravauxite[70] ($FeO \cdot Al_2O_3 \cdot P_2O_5 \cdot 5H_2O$?) is triclinic with $a : b : c = 0.506 : 1 : 0.688$, $\alpha = 97° 42'$, $\beta = 110° 22'$, $\gamma = 110° 56'$. Crystals prismatic with large 010 face and distinct 010 cleavage. H. = 3. G. = 2.29. Soluble in HCl. Sections parallel to 010 show an optic axis just outside the field and sections parallel to 100 show both optic axes just outside the field. On 010 $Y' \wedge c = 38°$, and on 100 $Y' \wedge c = -43°$. (+) 2V = 35°. $N_g = 1.573$, $N_m = 1.558$, $N_p = 1.554$, $N_g - N_p = 0.019$. Colorless. Found in ore deposits in Bolivia. Very rare.

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[70] S. G. Gordon: *Proc. Acad. Sci., Phila.*, LXXV, 1923, p. 261. In *Science*, LVI, 1922, p. 50, Gordon gave 2V = 32° for vauxite.

Borickite ($3CaO \cdot 7Fe_2O_3 \cdot 2P_2O_5 \cdot 24H_2O$) is apparently amorphous. H. = 3.5. G. = 2.7 ±. F. = 3–4. Soluble in acid. Isotropic with N = 1.57–1.67. Color reddish brown. Found in schist in Bohemia. Very rare. *Foucherite* [45] is similar, if not identical; N = 1.648.

Kehoeite $\{3(Zn,Ca)O \cdot 2Al_2O_3 \cdot P_2O_5 \cdot 27H_2O\}$ is apparently amorphous and chalky. G = 2.34. F. = 7. Soluble in acid. Isotropic with N = 1.53. Color white. Found in a lead deposit in South Dakota. Very rare.

16. PHOSPHATES, ETC., OF TRIVALENT, DIVALENT AND UNIVALENT BASES

Sicklerite $\{H_3Li_3Mn''_3Fe'''_2(PO_4)_8?\}$ is probably orthorhombic; two unequal cleavages at 90°. H. = 4. G. = 3.45. F. = easy. Soluble in acid. Axis Z normal to best cleavage. (−) 2V = rather large, $\rho > v$, very strong. $N_g = 1.745$, $N_m = 1.735$, $N_p = 1.715$, $N_g - N_p = 0.030$. Color dark brown; pleochroic from yellow to orange-red with $X > Y > Z$. Found in an ore deposit. Rare.

Lacroixite $\{Na_2(CaOH)(AlO)PO_4?\}$ is orthorhombic (?) with $a : b : c$ [71] = 0.796 : 1 : 1.568. Crystals pyramidal with 111 and $1\bar{1}1$ (but not $\bar{1}11$ and $\bar{1}\bar{1}1$) cleavages at an angle of 72°. H. = 4.5. G. = 3.13. Soluble in HCl. An optic axis is visible on (but oblique to) one cleavage. Optic sign unknown. 2V = large. $N_m = 1.57$, $N_g - N_p$ = distinct. Color pale yellowish or greenish. Found in pegmatite in Saxony. Very rare.

Morinite $\{HNa_2Ca_3Al_3F_6P_4O_{16} \cdot 8H_2O\}$ is monoclinic in lamellar masses. Poor 100 cleavage. H. = 4. G. = 2.94. F. = easy. Optic plane is 010; $X \wedge c = +30°$. (−) 2E = 40°. N = 1.555 ±, $N_g - N_p$ = about 0.01. Color wine- to flesh-red. An alteration product of amblygonite found in a tin deposit in France. Very rare.

Jezekite $\{Na_4(F,OH)_4CaAl(AlO)P_2O_8\}$ is monoclinic with $a : b : c = 0.896 : 1 : 1.024$, $\beta = 74° 29'$. Crystals prismatic and 100 tablets with perfect 100 and imperfect 001 cleavages. H. = 4.5. G. = 2.94. Optic plane is 010; $X \wedge c = +29°$. (−) 2V = medium. $N_g = 1.59$, $N_m = 1.58(?)$, $N_p = 1.55$, $N_g - N_p = 0.04$. Colorless. Found in pegmatite in Saxony. Very rare.

17. PHOSPHITES, ARSENITES, ANTIMONITES

Trippkeite (arsenite of Cu) is tetragonal with $c = 0.916$. Crystals pyramidal with perfect 100 and imperfect 110 cleavages. Soft. F. = easy. When heated in the closed tube it changes color, first to emerald green, then to brownish and finally to yellowish green. Easily soluble in acid. Uniaxial positive with $N_o = 1.90$, $N_e = 2.12$, $N_e - N_o = 0.22$. Color bluish green, not pleochroic. Crystals break easily into flexible fragments like asbestos. Found in druses in copper deposits. Very rare.

Ecdemite $\{Pb_6OCl(AsO_3)_2\}$ is tetragonal in acute pyramids or basal tablets. Distinct 001 cleavage. H. = 2.5. G. = 6.9–7.1. F. = easy. Soluble in HNO_3. Uniaxial negative with $N_o = 2.32$ Li, $N_e = 2.25$, $N_o - N_e = 0.07$. Color yellow or green. Also biaxial with two (or more) sets of lamellar twinning; this type, called *heliophyllite*, is regarded as orthorhombic with $a : b : c = 0.967 : 1 : 2.205$, isomorphous with ochrolite. Found in ore deposits in Sweden. Very rare.

Finnemanite [72] $\{Pb_5Cl(AsO_3)_3\}$ is hexagonal with $c = 0.688$. Crystals prismatic with distinct $10\bar{1}1$ cleavage. H. = 2.5. G. = 7.26. Uniaxial negative with N_o =

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[71] F. Slavik: *Bull. Intern. Acad. Sci., Bohême*, XX, 1916, p. 372; *Min. Abst.*, I, 1921, p. 257.

[72] G. Aminoff: *Geol. För. Förh.*, XLV, 1923, p. 160.

2.295, $N_e = 2.285$, $N_o - N_e = 0.010$. Color olive green. Found with hematite in ore deposits. Very rare.

Nadorite ($PbClSbO_2$) is a chloro-antimonite of lead which is orthorhombic with $a:b:c = 0.749:1:1.031$. Crystals 100 tablets, elongated parallel to c, with perfect 100 cleavage. Twinning on 011 at 91° 45′. H. = 4. G. = 7. F. = 1.5. Soluble in HCl. Optic plane is 010; X = a. (+) 2V = very large, $\rho > v$, strong. $N_g = 2.40$ Li, $N_m = 2.35$, $N_p = 2.30$, $N_g - N_p = 0.10$. Color smoky brown to brownish yellow. Found in zinc deposits in Algeria. Very rare.

Trigonite $\{HMnPb_3(AsO_3)_3\}$ is monoclinic[73] with $a:b:c = 1.074:1:1.659$, $\beta = 88° 29'$. Crystals clinohedral and wedge-shaped with perfect 010 and distinct 101 cleavages. H. = 2–3. G. = 8.28. Soluble in acid. Optic plane is 010; extinction in 010 at 45°. Optic sign unknown. $N_g = 2.16$, $N_m = 2.1 \pm$, $N_p = 2.08$, $N_g - N_p = 0.08$. Color sulphur yellow to brownish. Found in dolomite with native lead. Very rare.

18. HYPOPHOSPHATES

Schneebergite ($Ca_2Sb_2O_6$) is isometric and octahedral with distinct 111 cleavage. Closely related to *atopite*, but contains some FeO. H. = 6.5. G. = 5.4. F. = 7. Insoluble. Isotropic with N = 2.09, or weakly birefringent. Color honey yellow. Found with gypsum or anhydrite and chalcopyrite. Rare.

19. PYROPHOSPHATES, PYROANTIMONATES

Weslienite[74] ($Na_2Ca_3FeSb_4O_{15}$?) is isometric in complex crystals. H. = 6.5. G. = 4.97. Isotropic with N = 2.21. Also biaxial with undulatory extinction. Optically positive with large optic angle; abnormal bluish violet interference colors. Color yellow to brown. Found in ore deposits. Very rare.

Roméite ($Ca_5Sb_6O_{20}$) is pseudoisometric and octahedral with 111 cleavage. Tetragonal with $c = 1.026$. H. = 5.5–6. G. = 5. F. = difficult. Insoluble in acid. Isotropic with N varying from 1.82 to 1.87 and strongly dispersive with N = 1.824 for 762 $\mu\mu$, N = 1.8847 for 405 $\mu\mu$. Also uniaxial positive (Lacroix), an octahedron being composed of eight segments; four seen in a 100 section extinguish parallel to the edges. Each segment may show lamellar twinning with weak birefringence, apparently biaxial negative (Larsen). The index decreases with increase of sodium replacing calcium. Color yellow. Found in veins. Very rare.

Bindheimite ($Pb_2Sb_2O_7 \cdot nH_2O$) is opal-like. H. = 4. G. = 4.6–5. F. = 3–4. Anisotropic (when anhydrous?) with perfect prismatic cleavage and uniaxial negative with $N_o = 2.08$, $N_e = 1.82$, $N_o - N_e = 0.26$. Also often isotropic with N = 1.86 ±. Color gray, green, brown. Found in the oxide zone of antimony deposits. Rare.

Tripuhyite ($Fe_2Sb_2O_7$) is microcrystalline. G. = 5.82. F. = 4–5. (+)2V = small, $\rho < v$, very strong. $N_g = 2.33$, $N_m = 2.20$, $N_p = 2.19$, $N_g - N_p = 0.14$. Color dull greenish yellow. Found in gravels in Brazil. Very rare.

20. OTHER SALTS OF PHOSPHORUS, ARSENIC, VANADIUM, ETC.

Hewettite ($H_2CaV_6O_{17} \cdot 8H_2O$) is orthorhombic in slender blades. G. = 2.55. F. = easy to a red liquid. On heating loses water and changes color through shades of brown to bronze. Loss of $6H_2O$ does not destroy the crystal. Slightly soluble in water. Z parallel to elongation. (−) 2V = moderate. N_g = 2.35 (to 2.4), N_m = 2.18, N_p = 1.77 $N_g - N_p$ = 0.58. Color deep red with X and Y = very light orange-yellow, Z = dark red. Found in the oxide zone of vanadium deposits in Peru. Very rare.

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[73] G. Flink: *Geol. För. Förh., Stockholm,* XLII, 1920, p. 436.

[74] G. Flink: *Geol. För. Förh.,* XLV, 1923, p. 567.

Metahewettite has the same composition; it is orthorhombic (?) with $a : b$ = 0.65 : 1. G. = 2.51. F. = easy. On heating loses water and changes to yellow-brown. Loss of $6H_2O$ does not destroy the crystal. Crystals broad blades with X normal to blades and Z parallel to elongation. (−) 2V = 52°. N_g = 2.23 ±, N_m = 2.10, N_p = 1.70, $N_g - N_p$ = 0.53 ±. Color red with X = light orange yellow, Y = deep red, Z = deeper red. Found with hewettite. Very rare.

Pascoite $\{Ca_2V_6O_{17}\cdot 11(?)H_2O\}$ is monoclinic with poor 010 cleavage. H. = 2.5. G. = 2.46. F. = easy to a deep red liquid. Easily soluble in water. Optic plane and X normal to 010; strong crossed dispersion, Z in Li light making an angle of about 8° with Z in Na light. (−) 2V = 56° Li, 50½° Na. N_g = 1.825, N_m = 1.815, N_p = 1.775, $N_g - N_p$ = 0.050. Sections normal to X give no extinction and abnormal green and orange interference colors on account of the strong dispersion. Color orange, with X = light cadmium yellow, Y = cadmium-yellow, Z = orange. Found in the oxide zone of vanadium deposits in Pasco, Peru. Very rare.

Barthite $\{Zn_3Cu(OH)_4As_6O_{17}\}$ is monoclinic (?) in simple equant crystals apparently without cleavage. H. = 3. G. = 4.19. Crystals are zonal; the inner zone has (+) 2V = moderate, $\rho > v$, slight, N_g = 1.783, N_m = 1.774, N_p = 1.770, $N_g - N_p$ = 0.013; the outer zone has (+) 2V = nearly 90°, $\rho < v$, moderate, N_g = 1.815, N_m = 1.795, N_p = 1.780, $N_g - N_p$ = 0.035. Color grass green; in section inner zone nearly colorless, and outer zone yellowish green and faintly pleochroic. Found in dolomite in southwest Africa. Very rare.

21. PHOSPHATES, ETC., WITH SALTS OF OTHER OXYGEN ACIDS

For double salts consisting of sulphates, etc., with phosphates, see p. 118 *et seq.* Phosphates with minor amounts of carbonates or sulphates are included in the apatite group (see p. 128). Hydrated phosphates (with carbonate), closely related to apatite, include dahllite, francolite and collophanite.

Dahllite [75] $(Ca_7CO_3P_4O_{16}\cdot \frac{1}{2}H_2O)$ is hexagonal in fibrous crusts and masses. H. = 5. G. = 2.87–3.05. F. = 7. Soluble in cold acid. Uniaxial negative with N_o = 1.620 ±, N_e = 1.609, $N_o - N_e$ = 0.011 ±. N_o = 1.598 to 1.634, N_e = 1.592 to 1.627, $N_o - N_e$ = 0.006–0.019 (Böggild [76]). Fibers have positive elongation. Also distinctly biaxial with fibers elongated parallel to Y, and X and Z spirally arranged along the fibers (Lacroix). Found on apatite in Norway; as concretions in France. Rare.

Francolite $(Ca_{10}F_2CO_3P_6O_{24}\cdot H_2O)$ is hexagonal in basal plates, or fibrous (then called *staffelite*). H. = 4.5. G. = 3.1. F. = easy. Soluble in cold acid or ammonia. Uniaxial negative with N_o = 1.625, $N_o - N_e$ = weak. N_o = 1.614 to 1.627, $N_o - N_e$ = 0.004 to 0.009 (Böggild [76]). Also biaxial with X = *c* and 2V = small, the optic plane being parallel to the hexagonal edge in each of six segments seen in basal sections. Found in ore deposits and in phosphatic sediments. Not rare.

Dixenite $\{Mn_5(OH)_2SiO_3As_2O_6\}$ is hexagonal [73] and scaly with perfect 0001 cleavage. H. = 3–4. G. = 4.2. Decomposed by HCl. Uniaxial positive with N_o = 1.96, $N_e - N_o$ = ?. Color black; glowing red in transmitted light; in thin section orange yellow with no pleochroism. Found in hematite or dolomite. Very rare.

Tyrolite $\{(Cu,Ca)_6(OH)_4CO_3As_2(O,S)_8?\}$ is orthorhombic with $a : b$ = 0.933 : 1. Crystals basal plates elongated parallel to *b*; radiated laminæ. Perfect 001 cleavage.

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[75] Perhaps the same as carbapatite, see p. 128.

[76] *Zeit. Kryst.*, LX, 1924, p. 417.

H. = 1–1.5. G. = 3.1. F. = 2–2.5. Soluble in HNO_3 or NH_4OH. Optic plane is 010; X = *c*. (−) 2V = 36°, $\rho > v$, strong. $N_g = 1.730$, $N_m = 1.726$, $N_p = 1.694$, $N_g - N_p = 0.036$. Color pale green to sky blue with X = grass-green, Y = yellowish green, Z = grass-green. Found in copper deposits. Rare.

Lueneburgite ($3MgO \cdot B_2O_3 \cdot P_2O_5 \cdot 8H_2O$) is monoclinic. Crystals six-sided basal tablets elongated parallel to *a*. Distinct 110 cleavages at 73°. G. = 2.05. Fusible. Soluble in acid. Optic plane is 010(?); extinction (X and Z) at nearly 45° to elongation. (−) 2V = medium. $N_g = 1.545$, $N_m = 1.54$, $N_p = 1.520$, $N_g - N_p = 0.025$. Colorless. Found in marl of Lueneburg, Germany.

COLLOPHANITE (*Collophane*) $3Ca_3P_2O_6 \cdot Ca(CO_3,F_2,SO_4,O) \cdot nH_2O$

Comp.—The composition is variable, especially as to tenor of water. A variety containing fluorine is called *fluocollophanite*.

Phys. Char.—Layers or masses with conchoidal fracture. H. = 2 5. G. = 2.6 2.9. F. = 5–6. Soluble in cold HNO_3 with effervescence.

Opt. Prop.—Isotropic with N = 1.569 (Pouzillac—Lacroix [77]), 1.58 (Karyzek—Slavik [78]), 1.60 (Brezina—Slavik [78]), 1.605 (Morozewicz [79]), 1.612 (Rurutu—Lacroix [77]), 1.63 (Rogers [80]), 1.570–1.625 (Rogers [81]). Also weakly birefringent in some cases (due to strain?). Colorless or stained.

Occur.—The chief constituent of the extensive beds of rock-phosphate found in Utah, Wyoming, Montana, France, Algeria, etc.

Diag.—The easy solubility in cold acid without residue (and with effervescence) and the reactions for phosphates distinguish collophanite from opal and silicates.

Lewisite $\{(Ca,Fe)_5Sb_6Ti_4O_{24}?\}$ is isometric with distinct 111 cleavages. H. = 5.5. G. = 4.95. F. = easy. Insoluble in acid. Isotropic with N = 2.20. Color yellow to brown. Found in gravel of a mercury mine in Brazil. Very rare.

Derbylite ($Fe_6Sb_2Ti_5O_{21}$?) is orthorhombic with $a : b : c = 0.966 : 1 : 0.550$. Crystals prismatic; cruciform twinning common. H. = 5. G. = 4.52. F. = 7. Insoluble in acid. (+) 2V = nearly 0°. $N_g = 2.51$ Li, $N_m = 2.45$, $N_p = 2.45$, $N_g - N_p = 0.06$. Color black; in section dark brown and not pleochroic. Found in placers in Brazil. Very rare.

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[77] *Minéral., France*, IV, 1910, p. 561.

[78] *Bull. Intern. Acad. Bohême*, XXII, 1918, p. 32; *Min. Abst.*, I, 1921, p. 290.

[79] *Bull. Soc. Fr. Min.*, XLVII, 1924, p. 46.

[80] *Am. Jour. Sci.*, CCIII, 1922, p. 269.

[81] *Bull. Geol. Soc. Amer.*, XXXV, 1924, p. 535.

IX. COLUMBATES, TANTALATES AND TITANATES

Many of the minerals of this division are so rare and imperfectly known that it is not practicable to classify them on the basis of the valence of the bases, as in other divisions.

PEROVSKITE Isometric $CaTiO_3$

Phys. Char.—Crystals cubic, octahedral, tetrahedral, with poor cubic cleavage. Intimate penetration twinning on 111 and 110 common. H. = 5.5. G. = 4. F. = 7. Decomposed by H_2SO_4.

Opt. Prop.—Small crystals isotropic with N = 2.38. Large crystals anisotropic with complex twinning, like that of garnet or boracite, of orthorhombic units in which the optic plane[1] is 010 and $X = c$. $(+)2V$ = about 90°, $\rho > v$ about Z, $N_m = 2.38$, $N_g - N_p = 0.017$, or less. Color yellow, reddish, brown, black; in thin section gray, violet gray, brownish to reddish, rarely greenish; color may be arranged zonally.

Occur.—In metamorphic rocks, both regional and contact. Also in alkaline basalts. It may form by alteration of ilmenite.

Diag.—The extreme refringence, complex twinning in large crystals, color and weak birefringence are characteristic.

Knopite is closely related to perovskite, but contains some Ce_2O_3 and FeO. Isotropic with N = 2.30, or biaxial with strong birefringence. G. = 4.1–4.3. Color brown. Found in contact rocks. Very rare.

Pyrochlorite (*Pyrochlore*) is a titanate and columbate of sodium, calcium, cerium, iron, etc. It is isometric and octahedral with variable 111 cleavage. H. = 5. G. = 4.3. F. = 7, but turns green. Decomposed by H_2SO_4. Isotropic with N = 1.96 ± to 2.02 ±; may show yellow and brown zones in section. After ignition N = 2.27. Color brown or dark red. Found in igneous rocks. Very rare.

Dysanalite $\{(Ca,Fe)_7Cb_2Ti_6O_{24}?\}$ is isometric and cubic with cubic cleavage; related to perovskite and pyrochlorite. H. = 5–6. G. = 4.13. F. = 7. Decomposed by HCl. Isotropic with N = 2.33; nearly opaque in section. Also in part anisotropic and orthorhombic with the optic plane 001 and $Z = b$; $(+)$ 2V = nearly 90°, $N_m = 2.33$, $N_g - N_p$ = weak. Lamellar twinning and often zonal structure parallel to cubic faces. Color iron black, nearly opaque; also, X = light gray green, Z = dark gray green. Found in granular limestone. Very rare.

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[1] O. B. Böggild: *N. Jahrb. Min.*, 1912, II, p. 21; but H. L. Bowman (*Mineral. Mag.*, XV, 1909, p. 156) found the optic plane to be 001 and $X = a$; also $a : b : c = 1 : 1 : 0.707$.

Chalcolamprite $\{Na_4(CaF)_2Cb_2SiO_9?\}$ is isometric and octahedral. H. = 5.5. G. = 3.77. Isotropic with N = 1.87 ±. Color grayish brown with copper-red iridescence. Found with aegirite in Greenland. Very rare.

Samirésite is a columbate and titanate of uranium, lead, etc. Crystals octahedral. G. = 5.24. Isotropic with N = 1.92–1.96. Color golden yellow. Found in pegmatite in Madagascar. Very rare.

Betafite is a hydrous titanate and columbate of calcium, uranium, etc. Isometric and octahedral. H. = 5. G. = 4. Isotropic with N = 1.92 ±. Color greenish black. Found in pegmatite in Madagascar. Very rare.

Ellsworthite [2] ($CaCb_2O_6 \cdot 2H_2O$ with U, Fe''', Ti, etc.) is massive without cleavage. H. = 4. G. = 3.6–3.76. Isotropic with $N > 1.74$. Color amber-yellow or brown. Found in pegmatite. Very rare.

Microlite ($Ca_2Ta_2O_7$ with Na, Mg, F, etc.) is isometric and octahedral. H. = 5.5. G. = 5.5. F. = 7. Decomposed by H_2SO_4. Isotropic with N = 1.93. Color yellow, brown, red, etc. Found in pegmatite. Very rare.

Koppite ($Ca_2Ta_2O_7$ with Ce, Na, Fe, F, etc.) is isometric and dodecahedral. H. = 5.5. G. = 4.5. F. = 7. Decomposed by H_2SO_4. Isotropic with N = 2.15 ± (2.12 to 2.18). Color brown; in section red. Found in recrystallized limestone. Very rare. *Pyrrhite* is very similar in octahedral reddish crystals with N = 2.16.

Hatchettolite $\{U(Cb,Ta)_2O_7$, with Ca, Fe, etc.$\}$ is isometric and octahedral. H. = 5. G. = 4.8 ±. F. = 7. Insoluble in acid. Isotropic with N = 1.98 ±. Color brown; nearly colorless in section. Many birefringent shreds present (due to alteration?). Found in pegmatite in North Carolina. Very rare.

Neotantalite $\{H_2O,FeO,MnO,(Ta,Cb)_2O_5$, etc.$\}$ is isometric and octahedral. H. = 5 6. G. = 5.19. Isotropic with N = 1.96 ± (1.95 to 1.99). Color yellow. Found in tin-bearing sands in France. Very rare.

Tapiolite ($FeTa_2O_6$, with Cb, Mn) is tetragonal with $c = 0.646$. Crystals pyramidal with no good cleavage. Isomorphous with rutile. H. = 6. G. = 7.3–7.8. F. = 7. Uniaxial positive with $N_o = 2.27$ Li, $N_e = 2.42$, $N_e - N_o = 0.15$ (for crystal with G. = 7.4). Color black; in section red-brown with X = pale yellowish or reddish brown, Z = nearly opaque. Found in pegmatite in Finland. Very rare.

Strueverite $\{Fe(Ta,Cb)_2Ti_6O_{18}\}$ is tetragonal with $c = 0.646$; it is closely related to rutile. H. = 6. G. = 5.56. F. = 7. Uniaxial of unknown sign. $N_o = 2.50$ Li, $N_g - N_p$ = moderate. Color iron black with O = brown, E = green and nearly opaque. Found in pegmatite. Very rare.

Fergusonite $\{Y(Cb,Ta)O_4\}$ is tetragonal with $c = 1.464$; crystals pyramidal or prismatic with 111 cleavage in traces. Yttrium may be replaced, in part, by Er, Ce, Fe, Ca, etc. H = 6. G. = 5.8 (to 4.3, if hydrated). F. = 7. Attacked by H_2SO_4. Nearly always isotropic as a result of hydration with N = 2.10 ± to 2.19 ±. Color brown. When unaltered it is uniaxial negative with strong birefringence and distinct pleochroism according to Vogt. Found in pegmatite. Very rare.

Risoerite $\{Y(Ta,Cb)O_4\}$ is similar and, like fergusonite, may contain Ce, Ca, Er, etc.; it has Ti also. H. = 5.5. G. = 4.18. Soluble in H_2SO_4. Isotropic with N = 2.05. Color dark brown; reddish brown in section. Found in pegmatite. Very rare.

Sipylite ($ErCbO_4$) is similar with $c = 1.477$; crystals pyramidal with distinct 111 cleavage. H. = 6. G. = 4.89. F. = 7. Insoluble in acid. Isotropic with N = 2.06 ±. Color orange to black; pale red-brown in section. Very rare.

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[2] T. L. Walker and A. L. Parsons: *U. Toronto Studies, Geol. Ser.*, 16, 1923, p. 13.

COLUMBITE ORTHORHOMBIC $a : b : c = 0.829 : 1 : 0.890$ $(Fe,Mn)(Cb,Ta)_2O_6$

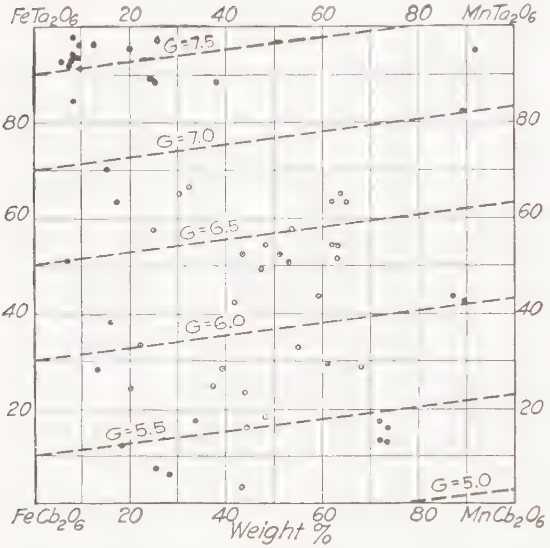

FIG. 80.—Variations in composition and specific gravity in the columbite-tantalite system. (Based on data of Mügge: *Cent. Mineral*, 1924, p. 417.)

COMP. — Columbite includes four subspecies, between which all gradations are possible, namely: *columbite* proper or *ferrocolumbite*, ($FeCb_2O_6$), *tantalite* proper or *ferrotantalite*, ($FeTa_2O_6$), *mangancolumbite*, ($MnCb_2O_6$) and mangantantalite, ($MnTa_2O_6$).

PHYS. CHAR.—Crystals short prisms or 100 tablets. Good 100 cleavage. H. = 6. G. = 5.35 for columbite proper, about 7.8 for tantalite, about 5.2 for mangancolumbite, and 7.3 for mangantantalite. F. = 7. Insoluble (columbite) to nearly insoluble (tantalite and mangantantalite) in acids.

OPT. PROP.—Optic orientation unknown because nearly opaque. Optic angle large, with sign positive in tantalite and probably negative in columbite.

The following data are given by Larsen:

Subspecies	Locality	G	Sign	2V	N_g	N_m	N_p	$N_g - N_p$
Mangancolumbite....	Canon City, Colo.	5.48	.....	....	....	2.45 Li	....	Strong
Columbite...........	Haddam, Conn.	?	(−?)	....	....	2.40 Li	....	Extreme
Tantalite............	South Dakota	?	(+)	Large	2.43	2.32	2.26	0.17
Tantalite............	Alabama	7.30	.....	....	2.3–2.4			
Mangantantalite.....	Amelia, Va.	6.5	(+)	Large $\rho < v$, moderate	2.34	2.25	2.19	0.15

Color black; the iron types nearly opaque even in thin section; the manganese types very dark red to brown with $X < Z$. In mangantantalite X = pale red, Y = blood red, Z = deep blood red.

OCCUR. Found in pegmatite in many places.

DIAG.—Distinguished from wolframite by inferior cleavage.

Hjelmite $\{Ca_4Ta_6O_{19}$(?) with Fe, Mn, U, Y, H, etc.$\}$ is orthorhombic with $a : b : c = 0.465 : 1 : 1.026$. Crystals indistinct. H. = 5. G. = 5.82. F. = 7. Nearly (or quite?) uniaxial; positive; $N_g = 2.40$, $N_m = 2.30$, $N_p = 2.30$, $N_g - N_p = 0.10$. Color black with X and Y = yellowish brown, Z = nearly opaque. Found in pegmatite in Sweden. Very rare.

Yttrotantalite $\{Y_4(Ta_2O_7)_3$(?) with Cb, Ca, Fe, H, etc.$\}$ is orthorhombic with $a : b : c = 0.541 : 1 : 1.133$. Crystals prismatic with poor 010 cleavage. H. = 5–5.5. G. = 5.5–5.9. F. = 7. Insoluble in acids. Isotropic with N = 2.15. Color black to yellow; red brown in section. Found in feldspar in Sweden, etc. Very rare.

Samarskite $\{Y_4(Cb_2O_7)_3(?)$ with Ta, Fe, U, Di, H, etc.$\}$ is orthorhombic with $a : b : c = 0.546 : 1 : 1.036$. Crystals elongated parallel to c with imperfect 010 cleavage. H. = 5–6. G. = 5.6–5.8. F. = 5. Nearly insoluble in acids. Isotropic with N = 2.10–2.25. Also strongly birefringent. Color velvet black; in section brownish to opaque. Found in pegmatite in North Carolina, etc. Rare.

Polycrasite is a columbate and titanate of rare earths; orthorhombic with $a : b : c = 0.379 : 1 : 0.355$. Crystals prisms or 010 tablets without cleavage. H. = 5–6. G. = 5.0. F. = 7. Decomposed by H_2SO_4. Isotropic (due to alteration?) with N = 1.70. Color dark brown to black; clear brown in section. Found in placers and pegmatite. Rare.

Blomstrandinite is a titanate and columbate of rare earths; orthorhombic with $a : b : c = 0.475 : 1 : 0.667$. Supposed to be dimorphous with euxenite. Crystals 010 tablets or square prisms parallel to a. Imperfect 010 cleavage. H. = 5.5. G. = 4.8–5.0. Isotropic (due to alteration?) with N = 2.14. After ignition N = 2.24. Color brownish black. Found in pegmatite in Norway. Very rare. Blomstrandinite is not the same as *blomstrandite*, which is a titanate and columbate of uranium, iron, calcium, etc. H. = 5.5. G. = 4.2. F. = 6. Isotropic with very high refringence. Color black; translucent and brown in thin splinters. Found in pegmatite. Very rare.

Ampangabeite is a columbate and titanate of uranium, iron, etc. Crystals seem orthorhombic in rectangular prisms. H. = 4. G. = 3.97–4.29. Fuses to brown slag. Soluble in HCl. Isotropic (due to alteration?) with N = 2.13. Color brownish red. Found in pegmatite in Madagascar. Very rare.

Wiikite is a columbate, titanate and silicate of iron and rare earths. It is probably orthorhombic with $a : b : c = 0.532 : 1 : 0.505$. H. = 6. G. = 3.8–4.8. F. = 7. Isotropic (due to alteration?) with N = 2.0 ± 0.04; birefringent in spots. Color black to brown and yellow. Found in pegmatite in Finland. Very rare.

Eschynite $\{(Ca,Fe)_2Ce_4Cb_6(Ti,Th)_8O_{39}?\}$ is orthorhombic with $a : b : c = 0.487 : 1 : 0.674$. Crystals prisms or 010 tablets. H. = 5.5. G. = 4.9–5.1. F. = 7. Insoluble in acid. Isotropic (due to alteration?) with N = 2.20–2.26. On ignition becomes birefringent with N = 2.285. Color brownish black; reddish brown in section. Found in pegmatite. Rare.

Polymignite $\{(Ca,Fe)_4(Ce,Y)_4Cb_2(Ti,Zr)_{10}O_{35}?\}$ is orthorhombic with $a : b : c = 0.712 : 1 : 0.512$. Crystals prismatic with 100 and 010 cleavages in traces. H. = 6.5. G. = 4.8. F. = 7. Isotropic (due to alteration?) with N = 2.215. Color black; dark brown in section. Found in pegmatite. Very rare.

Euxenite is a titanate and columbate of rare earths; orthorhombic with $a : b : c = 0.379 : 1 : 0.353$. Massive without cleavage. H. = 6.5. G. = 4.8. F. = 7. Insoluble in acid. Isotropic (due to alteration?) with N = 2.06 ± to 2.26 ±. Not always isotropic according to Lacroix. After ignition N = 2.23. Color brownish black; reddish brown in section. Found in pegmatite. Rare.

Yttrocrasite is an orthorhombic hydrous titanate of yttrium earths and thorium of doubtful purity. H. = 6. G. = 4.8. F. = 7. Soluble in H_2SO_4. Isotropic with N = 2.12 to 2.15, or faintly birefringent. Color black; amber color in section. Rare.

Stibiotantalite $\{Sb(Ta,Cb)O_4\}$ is orthorhombic with $a : b : c = 0.799 : 1 : 0.845$. Crystals prismatic or 100 plates with perfect 100 cleavage. Lamellar twinning on 100. H. = 5. G. = 6.6–7.9. F. = 4. Insoluble except in HF. A continuous series known from $SbTaO_4$ to $SbCbO_4$. In case Cb is dominant the mineral is called *stibiocolumbite*. With increase of Cb the indices and dispersion increase, and the density and birefringence decrease. For $Ta_2O_5 = 39\%$: G. = 6.82, $X = a$, $Z = c$, (+) $2V = 75°$, $\rho < v$ strong, $N_g = 2.457$ Na, $N_m = 2.404$, $N_p = 2.374$, $N_g - N_p = 0.083$. For $Ta_2O_5 = 22.5\%$ (*stibiocolumbite*): G. = 6.3, $X = a$, $Z = c$, (+) $2V = 73°$, $\rho < v$ strong, $N_g = 2.459$ Na, $N_m = 2.419$, $N_p = 2.398$, $N_g - N_p = 0.061$. Color dark brown, reddish or greenish yellow. Found in pegmatite. Very rare.

X. SILICATES

Titanosilicates, zirconosilicates, thorosilicates and stannosilicates as well as alumosilicates and borosilicates are included with ordinary silicates in this division. The classification of the silicates is still unsatisfactory because the minerals of a single isomorphous group may include two types of silicic acid and varying numbers of atoms of bases of varying valence. Recent X-ray work, which may lead to a new classification of silicates, indicates that forsterite is not composed of magnesium atoms with the orthosilicate radical (SiO_4), but of two MgO groups and the group SiO_2. For the present occasion the following classification is employed:

1. Silicates of monovalent bases without hydrogen.
2. Silicates of monovalent bases with hydrogen.
3. Anhydrous silicates of divalent bases (including the pyroxene and amphibole groups and excluding the melilite group).
4. Silicates of divalent bases with hydrogen, fluorine, chlorine, or sulphur.
5. Hydrous silicates of divalent bases.
6. Anhydrous silicates of trivalent bases.
7. Hydrous silicates of trivalent bases.
8. Silicates of divalent and monovalent bases.
9. Silicates of boron (and, or) rare earths and one or more other bases.
10. Anhydrous silicates of Al (Cr, Fe, Mn) and one or more other bases (including feldspars and feldspathoids).
11. Silicates of Al (Cr, Fe, Mn) and hydrogen or fluorine and one or more other bases.
12. Hydrous silicates of Al (Cr, Fe, Mn) and one or more other bases (zeolites).
13. Compounds consisting of silicates with salts of another oxygen acid.

1. SILICATES OF MONOVALENT BASES WITHOUT HYDROGEN

Lorenzenite ($Na_2Ti_2Si_2O_9$ with ZrO_2) is orthorhombic with $a : b : c = 0.604 : 1 : 0.359$. Crystals prismatic needles with distinct 120 cleavage. H. = 6. G. = 3.42. F. = easy. Insoluble in HCl. Optic plane is 100; Z = b. (+) 2E = 72°, N_g = 1.7786 Li, 1.7876 Na,

$N_m = 1.75 \pm$, $N_p = 1.7320$ Li, 1.7431 Na, $N_g - N_p = 0.0445$ Na. Colorless or stained. Found in pegmatite in Greenland. Very rare.

Ramsayite [1] ($Na_2Ti_2Si_2O_9$) is orthorhombic with $a : b : c = 0.605 : 1 : 0.600$. Perfect 100 and distinct 110 cleavages. H. = 6. G. = 3.43. F. = easy. Soluble in HF. Optic plane is 010; $X = a$. (−) $2E = 50°$, $\rho > v$, strong. $N_m = 1.9 \pm$, $N_g - N_p = 0.091$. Color brown to black with X = Y = pale orange, Z = pale yellow. Found in pegmatite. Rare.

2. SILICATES OF MONOVALENT BASES WITH HYDROGEN

Elpidite ($H_6Na_2ZrSi_6O_{18}$) is orthorhombic with $a : b : c = 0.510 : 1 : 0.978$. Crystals fibrous with 110 cleavages. H. = 7. G. = 2.58. Optic plane is 010; $Z = a$; elongation negative. (+) $2V = 75° \pm$, $\rho < v$ distinct. $N_g = 1.574$, $N_m = 1.565$, $N_p = 1.560$, $N_g - N_p = 0.014$. Color white to brick red. Found in pegmatite in Greenland. Very rare. Lacroix has described a similar mineral [1a] with refringence less than that of albite and 2V variable to 89°.

Titano-elpidite [1b] ($H_6Na_2TiSi_6O_{18}$) is similar. Crystals prismatic with H. = 6.5, G. = 2.55. Optic plane is 001; $X = b$. (+) 2V = moderate, $\rho > v$. $N_g = 1.698$, $N_m = 1.686$, $N_p = 1.681$, $N_g - N_p = 0.017$. Color brown with Y = yellow, X = colorless. Found in a contact with albite.

Catapleite ($H_4Na_2ZrSi_3O_{11}$ usually with Ca) is monoclinic with $a : b : c = 1.733 : 1 : 1.362$, $\beta = 89° \ 49'$; pseudohexagonal with $c = 1.361$; strictly hexagonal above about 140° C. Crystals thin 001 plates with pseudohexagonal twinning on 110; perfect 110 and 010 cleavages. H. = 6. G. = 2.75. F. = 3. Soluble in HCl. Optic plane is 010; Z nearly normal to 001. (+) $2E = 30°–60°$, $\rho < v$, weak. 2E decreases with heat, becoming 0° at about 140° C. $N_g = 1.627$, $N_m = 1.592$, $N_p = 1.591$, $N_g - N_p = 0.028$. Color yellow to brown; bluish. Found in pegmatite. Very rare.

"**Catapleite**" from Greenland is described [2] as orthorhombic with $a : b : c = 1.727 : 1 : 1.336$, and G = 2.66. The optic plane is 010; $X = c$. (−) 2V = large. $N_g = 1.605$, $N_m = 1.590$, $N_p = 1.575$, $N_g - N_p = 0.030$. Colorless or buff.

3. ANHYDROUS SILICATES OF DIVALENT BASES (INCLUDING THE PYROXENE AND AMPHIBOLE GROUPS, AND EXCLUDING THE MELILITE GROUP)

Phenacite (Be_2SiO_4) is trigonal with $c = 0.661$. Crystals rhombohedral or prismatic; twinning common on $10\bar{1}0$. Distinct $11\bar{2}0$ cleavages. H. = 7.5. G. = 3.0. F. = 7. Insoluble in acid. Uniaxial positive with $N_o = 1.654$ Na, $N_e = 1.670$, $N_e - N_o = 0.016$. Colorless, yellow, rose, brown; may be faintly pleochroic. Found in pegmatite and some metamorphic rocks. Rare.

Willemite (Zn_2SiO_4) is trigonal with $c = 0.670$. Crystals hexagonal prisms with variable 0001 and $11\bar{2}0$ cleavages. H. = 5.5. G. = 3.9–4.1. F. = 1510° C. Gelatinizes with HCl. Uniaxial positive with $N_o = 1.694$ Na, $N_e = 1.723$, $N_e - N_o = 0.029$ (Palache); $N_o = 1.693$, $N_e = 1.712$, $N_e - N_o = 0.019$ (Gaubert); $N_o = 1.697$, $N_e =$

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[1] E. E. Kostyleva: *Min. Abst.*, II, 1924, p. 250. A. E. Fersman: *Am. Mineral.*, XI, 1926, p. 289.

[1a] A. Lacroix: *Comp. Rend.*, CLXXIII, p. 267; Böggild: *Medd. Grönl.*, XXXIII, p. 118.

[1b] A. E. Fersman: *Am. Mineral.*, XI, 1926, p. 289.

[2] S. G. Gordon: *Proc. Phila. Acad. Sci.*, LXXVI, 1924, p. 258.

1.719, $N_e - N_o = 0.022$ (Jaeger [2a]). Color white, green, red, gray, etc. A reddish or gray variety containing manganese is known as *troostite*. Found in zinc deposits. Uncommon.

Barysilite ($Pb_3Si_2O_7$) is trigonal with $c = 0.486$. Crystals rhombohedral in basal tablets with distinct 0001 cleavage. H. = 3. G. = 6.72. F. = 2.5. Gelatinizes with HNO_3. Uniaxial negative with $N_o = 2.07$, $N_e = 2.05$, $N_o - N_e = 0.02$. Colorless. Found in ore deposits. Rare.

Benitoite ($BaTiSi_3O_9$) is trigonal with $c = 0.732$; crystals pyramidal or tabular with difficult $10\bar{1}1$ cleavages. H. = 6-6.5. G. = 3.65. F. = 3, to transparent glass. Soluble in HF. Uniaxial positive with $N_o = 1.757$, $N_e = 1.804$, $N_e - N_o = 0.047$. Color blue, purple, colorless, varying even in a single crystal. Colored parts pleochroic with X = colorless, Z = purple, indigo or greenish blue. Found in veins or geodes with natrolite in glaucophane schist in serpentine. Very rare.

Gillespite ($Fe''BaSi_4O_{10}$) is hexagonal (?) with perfect basal cleavage. H. = 3. G. = 3.33. F. = easy. Attacked by HCl. Uniaxial negative with $N_o = 1.621$, $N_e = 1.619$, $N_o - N_e = 0.002$. Color rose red with X = deep rose red, Z = pale pink. Found in pegmatite(?). Very rare.

Barylite [2b] ($Be_2BaSi_2O_7$) is orthorhombic with $a : b : c = 0.803 : 1 : 0.838$. Crystals prismatic or tabular with good 001 and 012 and less distinct 100 and 010 cleavages. H. = 7. G. = 4. F. = 7. Insoluble. Optic plane is 100; $X = b$. (+) $2V = 65°$, $\rho > v$ weak. $N_g = 1.695$, $N_m = 1.685$, $N_p = 1.681$, $N_g - N_p = 0.014$ (Weibull). (+) $2V = 81°$, $N_g = 1.703$, $N_m = 1.696$, $N_p = 1.691$, $N_g - N_p = 0.012$ (Aminoff [2b]). Color milk white. Found in limestone in Sweden. Very rare.

OLIVINE GROUP

The minerals of the olivine group are orthosilicates of divalent bases crystallizing in the orthorhombic system. They occur commonly as embedded grains or short prismatic crystals terminated by pyramids and domes. They have high refringence and strong birefringence with a large optic angle. They are readily attacked by acids with gelatinization; they alter very easily both under hydrothermal and atmospheric conditions. The chief types are the following:

Species	Subspecies	Formula	$a : b : c$
Shannonite [3]		Ca_2SiO_4	
	(Artificial)	$CaFeSiO_4$	0.437 : 1 : 0.577
	Glaucochroite	$CaMnSiO_4$	0.441 : 1 : 0.581
	Monticellite	$CaMgSiO_4$	0.434 : 1 : 0.576
Olivine proper	Forsterite	Mg_2SiO_4	0.467 : 1 : 0.587
	Chrysolite	$(Mg,Fe)_2SiO_4$	0.466 : 1 : 0.586
	Fayalite	Fe_2SiO_4	0.458 : 1 : 0.579
	Knebelite	$(Mn,Fe)_2SiO_4$	0.467 : 1 : ?
	Tephroite	Mn_2SiO_4	0.462 : 1 : 0.591
	Picrotephroite	$(Mn,Mg)_2SiO_4$	?

[2a] *Proc. K. Akad. Wet. Amst.*, XVIII, 1916, p. 896. *Tables Ann. Int. Constantes*, IV, 1922, p. 1068.

[2b] G. Aminoff: *Geol. För. Förh.*, XLV, 1923, p. 124.

[3] This name is here suggested for "lime-olivine"; it is derived from the locality, Shannon Tier, Tasmania, where the mineral was first found by F. P. Paul (*Tsch. Mineral. Pet. Mitth.*, XXV, 1906, p. 309).

It is believed that glaucochroite and monticellite are double salts and not mix crystals; natural crystals show very little miscibility of Ca_2SiO_4 and Fe_2SiO_4, but the double salt has been found in slags, therefore shannonite, like calcite, is a species. Glaucochroite and monticellite show considerable natural solubility in artificial melts and it is possible that $CaMnSiO_4$, $CaMgSiO_4$, and $CaFeSiO_4$ are all miscible in all proportions, like the three types of dolomite. It is clear that forsterite is miscible in large and probably in all proportions [4] in fayalite, intermediate types rich in magnesia being known as chrysolite or olivine proper. Fayalite is also probably miscible in all proportions with tephroite, knebelite being an intermediate type. Forsterite and tephroite are also probably miscible in all proportions, though such mix-crystals (called picrotephroite) are rare.

SHANNONITE Orthorhombic Ca_2SiO_4

Phys. Char.—Crystals prismatic, also granular. Distinct 010 and 100 cleavages. H. = 5-6. F. = 2130° C. Strongly attacked by water with solution of lime. Readily soluble in weak HCl.

Opt. Prop.—The optic plane is parallel to 100; the axis X is parallel to the elongation (*c*). (+) $2V = 64°$, $\rho > v$, $N_g = 1.746$, $N_m = 1.738$, $N_p = 1.718$, $N_g - N_p = 0.028$. Colorless or light gray in section.

Occur.—In nephelite-eudialite-basalt in Tasmania [5] and in melilite-nephelite-basalt in Quebec.[6] Very rare.

GLAUCOCHROITE Orth. $a : b : c = 0.441 : 1 : 0.581$ $CaMnSiO_4$

Phys. Char.—Crystals prismatic; also in grains. Poor 001 cleavage. H. = 6. G. = 3.41. F. = 3.5. Gelatinizes with HCl.

Opt. Prop.—The optic plane is parallel to 001; X is normal to 010. (−) $2V = 60° 51'$, $\rho > v$ marked. $N_g = 1.735$, $N_m = 1.722$, $N_p = 1.686$, $N_g - N_p = 0.049$. Also: $N_g = 1.729$, $N_m = 1.716$, $N_p = 1.679$, $N_g - N_p = 0.050$.

Color bluish green; colorless in section.

Occur.—At Franklin Furnace, N. J., with garnet, etc. Very rare.

MONTICELLITE Orth. $a : b : c = 0.434 : 1 : 0.576$ $CaMgSiO_4$

Phys. Char.—Crystals prismatic; also granular. Poor 010 cleavage. H. = 5-5.5. G. = 3.2. F. = 6. Gelatinizes with HCl.

Opt. Prop.—The optic plane is parallel to 001; X = *b*. (−) $2V = 75° 42'$ Li, $75° 2'$ Na, $72° 56'$ Tl. $N_g = 1.6679$ Na, $N_m = 1.6594$ Li, 1.6616 Na, 1.6653 Tl, $N_p = 1.6505$ Na, $N_g - N_p = 0.0174$ Na. (Data from Ark. mineral with 4.75 FeO and 1.62 MnO.)

Colorless or grayish; colorless in section.

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[4] If a gap in the miscibility occurs (which would be near fayalite) as believed by Pöschl (*Tsch. Mineral. Pet. Mitth.*, XXVI, p. 413) and Thaddieff (*Zeit. Kryst.*, XXVI, 1896, p. 28), chrysolite would be a species and forsterite a subspecies.

[5] F. P. Paul: *Tsch. Min. Pet. Mit.*, XXV, 1906, p. 309.

[6] N. L. Bowen: *Am. Jour. Sci.*, CCIII, 1922, p. 30.

ALTER.—Changes to serpentine and to *fassaite*, a variety of augite.

OCCUR.—In limestone and igneous rocks near contacts. Rare.

DIAG.—Differs from chrysolite by weaker birefringence and poor cleavage; most chrysolite is positive.

FORSTERITE ORTH. $a : b : c = 0.467 : 1 : 0.587$ Mg_2SiO_4

PHYS. CHAR.—Crystals equant or somewhat flattened parallel to 100 or elongated parallel to *c*; also granular. Twinning on 031 rare. Distinct 010 and 001 cleavages. H. = 6–7. G. = 3.217. F. = 1890° C. Gelatinizes with HCl.

OPT. PROP.—The optic plane is parallel to 001; the acute bisectrix Z is normal to 100. $(+)2V = 85° \ 16'$, $\rho < v$. $N_g = 1.670$, $N_m = 1.651$, $N_p = 1.635$, $N_g - N_p = 0.035$. Color white, yellowish, greenish; colorless in section.

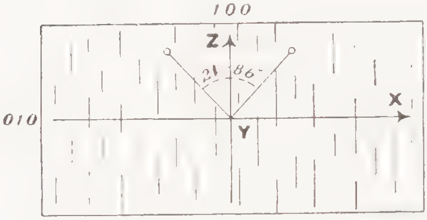


FIG. 81.—Optic orientation of forsterite.

ALTER.—Hydrates to serpentine very easily.

OCCUR.—Produced by contact metamorphism of dolomite.

DIAG.—Distinguished from chrysolite only by accurate measures of indices, of density, of optic angle, or of composition. The mode of occurrence is distinctive.

CHRYSOLITE (*Olivine proper*) ORTHORHOMBIC $(Mg,Fe)_2SiO_4$

$a : b : c = 0.466 : 1 : 0.586$

PHYS. CHAR.—Crystals usually somewhat elongated parallel to *c*; rarely parallel to *a*; commonly with good development of 110, 010, 021, 100, 101, etc.; also granular massive. Twinning rare on 011; very rare on 012. Distinct 010 and less distinct 100 cleavages. H. = 6.5–7. G. = 3.2–3.34. F. = 7, but varieties rich in iron (*hyalosiderite* with Mg : Fe = 2 : 1, for example) fuse at 6 to a black magnetic globule. Very easily attacked by acid (even acetic) with gelatinization.

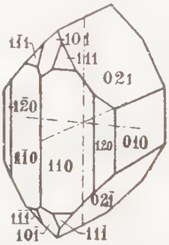
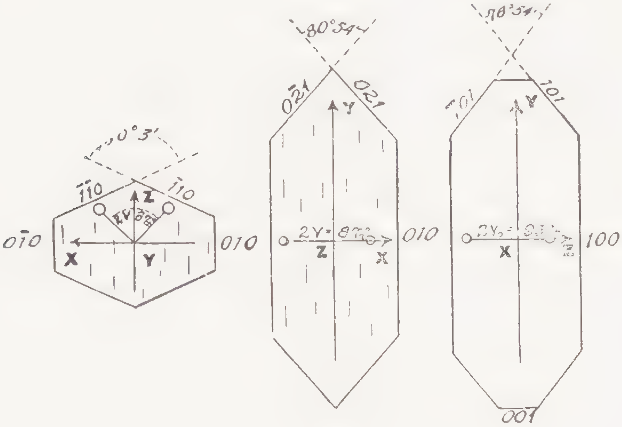


FIG. 82.—A crystal habit of olivine.

OPT. PROP.—The plane of the optic axes is parallel to 001; the bisectrix X is normal to 010. The optic angle is very large with weak dispersion $\rho < v$ about Z. Most chrysolite is positive, but 2V passes 90° at about 13 per cent

FeO; with more FeO the mineral is negative. The relations between composition and optic properties are shown in Fig. 86. For the common types: (+) 2V = 70°–90°, N_g = 1.67–1.69, N_m = 1.65–1.67,



FIGS. 83–85.—Optic orientation of olivine.

N_p = 1.635–1.655, $N_g - N_p$ = 0.035 ±. For more ferriferous types: (−) 2V = 90°–75°, N_g = 1.69–1.75, N_m = 1.67–1.75, N_p = 1.655–1.72, $N_g - N_p$ = 0.035–0.040.

Color olive green; by alteration becomes yellow, brown, or red. Colorless to very pale greenish in section, without pleochroism. By alteration of the iron it becomes yellowish to red.

INCL.—Inclusions are common of magnetite, spinel, apatite, and of vitreous, liquid or gaseous nature. Movable bubbles of liquid carbon dioxide are sometimes observed in cavities in olivine.

ALTER.—Olivine alters very readily; indeed, it is much more commonly found altered than fresh. The alteration may give varying products, as follows: The commonest alteration product of olivine is antigorite (or chrysotilite). In this case the olivine is changed to a hydrous magnesium silicate with, frequently, the separation of magnetite or hematite. Along the cleavage and fracture lines, which open markedly, the antigorite develops in fibers or laminæ; finally the whole mass is transformed. Quite often olivine alters to a mineral probably related to antigorite, but containing considerable iron and showing distinct optical properties. This alteration may result in fibers or laminæ, or it may result in a compact mineral having the same orientation as the original crystal of olivine. The resultant

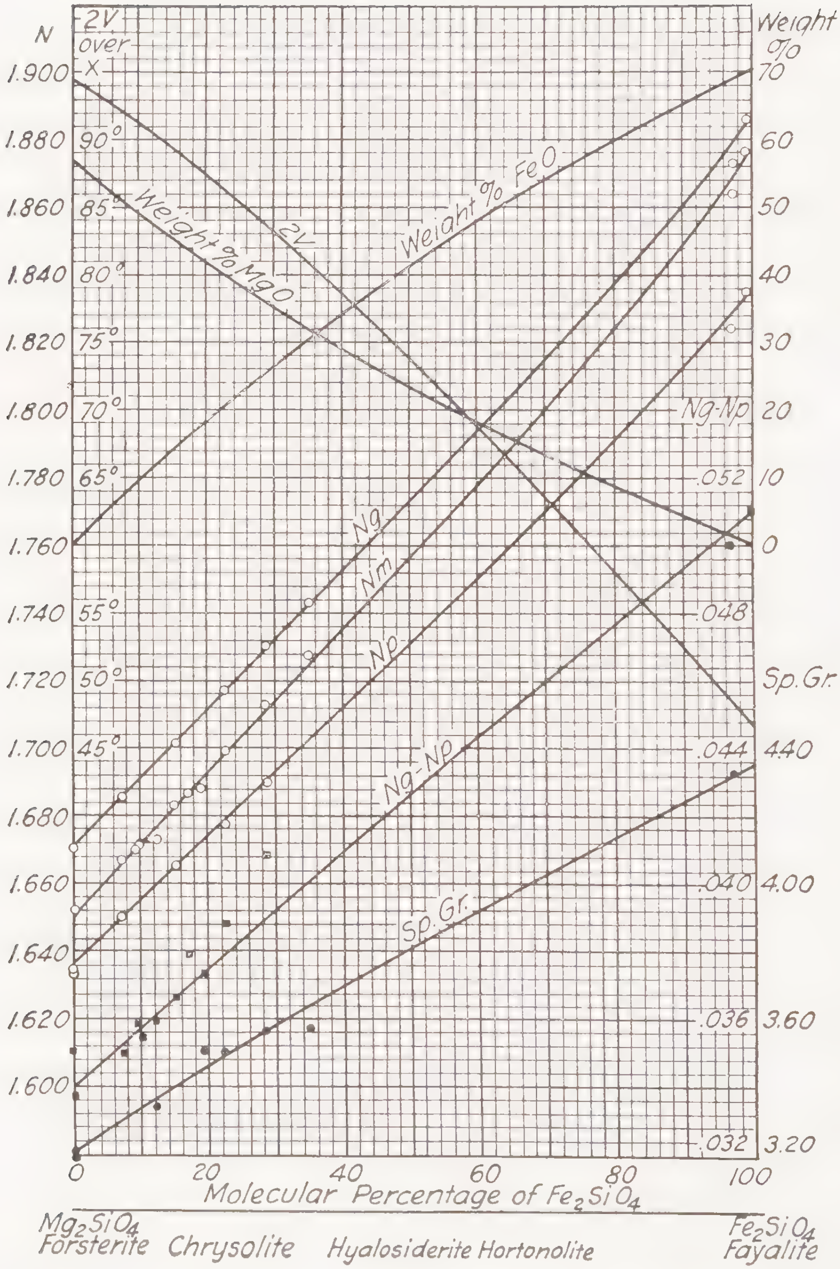


Fig. 86.—Variations in composition and optic properties in the forsterite-fayalite series.

mineral may be *bowlingite*, *xylotilite*, or (with nickel) *garnierite*. Antigorite and chrysotilite in thin section are colorless or very pale green with weak birefringence; bowlingite and xylotilite are yellow to brown and pleochroic with strong birefringence, while garnierite is bright green.

Another type of alteration quite common in olivine is the change to hematite, or limonite, or goethite. In this case the alteration takes place along cleavage and fracture lines, even when they are not opened, or it may attack the mineral with no reference to the cleavage lines on the borders or elsewhere.

Atmospheric weathering of olivine results in the formation of antigorite or carbonates with limonite and opal (or quartz). The carbonate is often calcite, showing the removal of Mg and its replacement by Ca.

Regional metamorphism sometimes changes olivine to an amphibole. This occurs only when the olivine is in contact with feldspar, and thus the pale green to colorless amphibole needles form a zone between the olivine and feldspar. More rarely still, other minerals may form from olivine, as pyroxene, talc, etc.

Occur.—Olivine is a common constituent of various igneous rocks, in some of which it is an essential part. It is found especially in basic igneous rocks where it is commonly associated with augite, hypersthene, plagioclase feldspar, magnetite, etc. Further, it is not uncommon in crystalline limestone and dolomite; varieties poor in iron are usually found here. It is occasionally found in small amount in ore deposits. Finally, olivine is an essential constituent of many meteorites, where it constitutes (with enstatite, chromite, etc.) the stony portion of the mass.

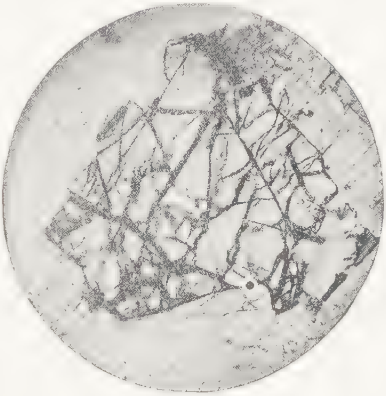


Fig. 87.—Photomicrograph of olivine in thin section.

Diag.—Olivine is easily recognized. When in crystals the sections show acute-angled ends, a high refringence, a shagreen surface, no color, strong birefringence, and a large optic angle. Extinction in the chief zones occurs parallel to the elongation and to the cleavages. It is distinguished from diopside by poorer and unequal cleavages to which the extinction is parallel. It is difficult to distinguish from orthorhombic humite when the crystal form is lacking without a chemical test for fluorine; however, the optic plane is normal to the best cleavage in olivine and parallel to the cleavage in humite.

FAYALITE ORTH. $a : b : c = 0.458 : 1 : 0.579$ Fe_2SiO_4

PHYS. CHAR.—Crystals 100 tablets or forms similar to chrysolite. Twinning rare on 011. Distinct 010 and poor 100 cleavages. H. = 6.5. G. = 4.32. F. = 4 to black magnetic globule. Gelatinizes with HCl.

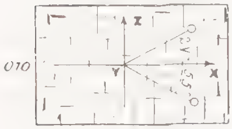


FIG. 88.—Optic orientation of fayalite.

OPT. PROP.—The plane of the optic axes is parallel to 001; the acute bisectrix X is normal to 010. Refringence very high; birefringence very strong. Optic axial angle moderate with distinct dispersion, $\rho > v$, about X.

$$(-)\ 2V = 47°\text{–}50° +,\ \rho > v \text{ distinct.}$$
$$N_g = 1.886,\quad N_m = 1.877,\quad N_p = 1.835,\quad N_g - N_p = 0.051.$$

The optic angle becomes larger and the refringence and birefringence decrease as iron is replaced by magnesium (see chrysolite). In the variety *hortonolite* with about 6 per cent Mn_2SiO_4 and 25 per cent Mg_2SiO_4, the optic angle (2V) is about 70° and $N_g = 1.8031$, $N_m = 1.7915$, $N_p = 1.7684$. The birefringence (0.0347) derived from these figures is probably too low.

Color pale greenish yellow; by oxidation of iron it becomes reddish brown to black. Usually colorless in thin sections, but may be pale yellow with X = Z = greenish yellow, Y = orange yellow, and Y > X > Z. The pleochroism may be due to ferruginous inclusions in some cases.

ALTER.—Similar to chrysolite, but iron minerals are more abundant.

OCCUR.—Not abundant in nature; found in lithophysæ in rhyolite from Yellowstone Park, etc.; also in other volcanic rocks, in pegmatites, and in some igneous rocks rich in iron of the Lake Superior region. Fayalite is the most abundant silicate found crystallized in many metallurgical slags in which it exhibits all the forms common in chrysolite; a vitreous residue is common in fayalite thus formed.

Diag.—See chrysolite. Fayalite differs from chrysolite in having higher relief, stronger birefringence, smaller optic angle and lower fusibility. Further, most chrysolite is positive.

KNEBELITE

Orth. $a : b : c = 0.467 : 1 : ?$ $(Mn,Fe)_2SiO_4$

Phys. Char.—Crystals rare, similar to chrysolite. Distinct 110 and poor 100 and 001 cleavages. H. = 6.5. G. = 3.9-4.17. F. = 3. Gelatinizes with HCl.

Opt. Prop.—The optic plane is parallel to 001; the acute bisectrix X is normal to 010.[7] Refringence very high; birefringence strong. The following data illustrate the variations of optic properties with variations in composition.

Fe_2SiO_4	Mn_2SiO_4	Mg_2SiO_4	2V	N_g	N_m	N_p	N_g-N_p	Locality	Authority
100	....	....	47°	1.886	1.877	(1.835)	(0.051)	Hoffnung slag	Busz [8]
87.1	7.2	5.7	51° 18′	1.873	1.864	1.823	0.050	Gillinge	Magnusson [9]
74.5	25.5	....	......	1.846	1.836	1.805	0.041	Hoffnung slag	Busz [8]
65.7	26.7	7.5	54°	1.847	1.838	1.805	0.042	Silvberg	Magnusson [9]
50.9	46.7	2.4	56°	.....	.....	....	....	Dannemora	Magnusson [9]
......	92.2	7.8	65° 18′	1.797	1.786	1.759	0.038	Pajsberg	Magnusson [9]

Color gray, red, brown, yellow, green, black; colorless to pale yellow in section; brown or green from alteration; in thick plates the mineral from Gillinge has X and Z = yellowish white, Y = pale yellow and Y > X = Z.

Roepperite is a variety containing about 17. MnO and 10. ZnO; it has distinct 010 and 001 cleavages. G. = 4. Optic plane is 001; X = *b*. (−) 2V = 77°, $\rho > v$, distinct. $N_g = 1.804$, $N_m = 1.786$, $N_p = 1.758$, $N_g - N_p = 0.046$. Found at Franklin, N. J. Very rare.

Alter.—Similar to chrysolite and tephroite.

Occur.—In iron-manganese deposits in Scandinavia. Rare.

TEPHROITE

Orth. $a : b : c = 0.462 : 1 : 0.591$ Mn_2SiO_4

Phys. Char.—Crystals like chrysolite, but rare. Distinct 010 and poor 100 cleavages. H. = 6. G. = 4.1. F. = 3.5 to a black scoria. Gelatinizes with HCl.

Opt. Prop.—The optic plane is parallel to 001; the acute bisectrix X is normal to 010. Refringence very high; birefringence strong. On tephroite with 7.8 Mg_2SiO_4: (−) 2V = 65° 18′, $\rho > v$, distinct. $N_g = 1.797$, $N_m = 1.786$, $N_p = 1.759$, $N_g - N_p = 0.038$.

On tephroite from Franklin, N. J.; (containing zinc?), Larsen obtained: (−) 2V = large, $\rho > v$, $N_g = 1.804$, $N_m = 1.792$, $N_p = 1.770$, $N_g - N_p = 0.034$.

Color ash gray (whence the name), grayish red, reddish brown, rose red. In thin section nearly colorless; in thick sections X = brownish red, Y = reddish, Z = greenish blue and X < Z < Y.

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[7] Incorrectly given as 100 commonly.

[8] K. Busz and F. W. Rüsberg: *Cent. Mineral.*, 1913, p. 625.

[9] H. Magnusson: *Geol. För. Förh. Stockholm*, XL, 1918, p. 601.

INCL.—May occur intergrown with franklinite, willemite and rhodonite.

OCCUR.—In ore deposits of manganese, iron and zinc at Franklin, N. J.; in manganese deposits and contact rocks in Sweden, etc. Rare.

DIAG.—Easily recognized as an olivine; differs from other olivines in pleochroism and reactions for manganese.

Picrotephroite $\{(Mn,Mg)_2SiO_4\}$ is the name of the series between tephroite and forsterite rich in manganese. A sample [9] from Langban, Sweden, with 40.4 Mg_2SiO_4 and 59.6 Mn_2SiO_4 has good 001 and 010 and poor 100 cleavages. (−) $2V = 85° 20'$, $N_g = 1.740$, $N_m = 1.727$, $N_p = 1.711$, $N_g - N_p = 0.029$. Color red brown; nearly colorless in section. Very rare.

PYROXENE GROUP

The minerals of the pyroxene group are very closely related in crystallographic and other physical characters, as well as in chemical composition, although they crystallize in three different systems (orthorhombic, monoclinic and triclinic). In all of them the fundamental and common form is the unit prism with interfacial angles of about 87° and 93°, while parallel to both prism faces there are distinct cleavages. Chemically the pyroxenes are metasilicates of magnesium, iron, manganese and calcium with double silicates of sodium or lithium with aluminum or ferric iron.

PHYS. CHAR.—The pyroxenes commonly crystallize in rather short prismatic forms with good 110 cleavages, and twinning, not rare, on 100. They have a hardness of 5 to 7, and a density of 2.8 to 3.7.

OPT. PROP.—The plane of the optic axes is parallel to 010 in orthorhombic and most monoclinic pyroxenes; and in the latter the axis Z makes with the vertical axis c an angle of 26° to 95° in the obtuse angle β. These angles are shown in Fig. 89. Pyroxenes may have parting parallel to 100 or to 001. The relief is always quite distinct and the birefringence varies from 0.009 in enstatite to 0.029 in diopside and 0.052 in acmite. The angle of the optic axes is usually large (54° to 90°), but in pigeonite it is very small.

Color black, green, brown, yellow, white, blue. In thin section usually pale to colorless with pleochroism very weak or absent. But sodiferous pyroxenes have a distinct green color and pleochroism, and other special types (like titanaugite) have peculiar colors.

ALTER.—Pyroxenes alter quite readily, especially to amphibole and chlorite.

OCCUR.—Pyroxenes are essential constituents of many igneous rocks, and occur in nearly all such rocks. They are also found in various metamorphic rocks, both regional and contact, and in meteorites.

DIAG.—The pyroxenes differ from amphiboles as follows:

Pyroxenes	Amphiboles
Cleavage angle about 93°.	Cleavage angle about 124°.
Crystals usually short prismatic.	Crystals usually long prismatic.
Maximum extinction angle in vertical zone 30°–54° (except certain alkaline types with unusual colors).	Maximum extinction angle in vertical zone 0°–25° (except certain alkaline types with unusual colors).
Most species positive.	Most species negative.
Color and pleochroism usually weak.	Color and pleochroism usually marked.
Alter to amphibole, etc.	Alter to chlorite, etc. (Change to pyroxene only through fusion.)

CLASS.—The pyroxenes naturally fall into three divisions, namely, those of orthorhombic symmetry, those of monoclinic, and those of triclinic. The orthorhombic pyroxenes belong to a single continuous isomorphous series which begins with pure magnesium metasilicate (enstatite) and ends with ferriferous magnesium metasilicate (hypersthene). The series as a whole has been called enstenite.

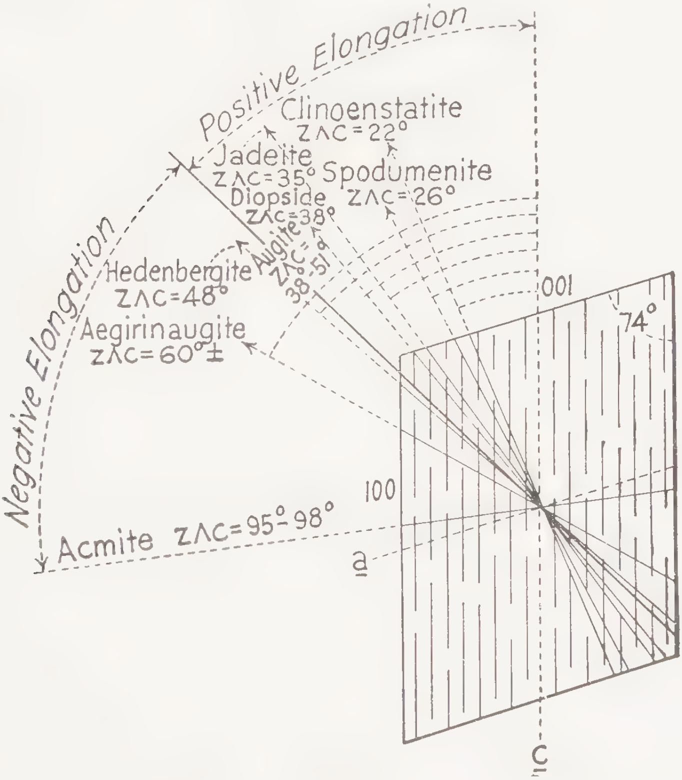

FIG. 89.—Diagram of the extinction angles (Z ∧ c) in monoclinic pyroxenes.

The monoclinic pyroxenes consist of magnesium metasilicate (clinoenstatite), ferriferous magnesium metasilicate (clinohypersthene), and metasilicates of calcium-magnesium (diopside), calcium-iron (hedenbergite), sodium-iron (acmite), sodium-aluminum (jadeite), and lithium-aluminum (spodumenite); some of them may contain important amounts of alumina or iron sesquioxide or both (augite). Clinoenstatite and clinohypersthene form a continuous isomorphous series[10] (*clinoenstenite*) like the orthorhombic series. It has been demonstrated experimentally that clinoenstatite and diopside are miscible (*at high temperatures*) in all proportions,[11] it has long been known that there is a continuous series from diopside to hedenbergite, and it is highly probable that all types of clinoenstenite are miscible (*at high temperatures*) in all types of the diopside-hedenbergite series. Limited amounts (up to 15 or 20 per cent) of sesquioxides are miscible[12] in this double series, making the types called augite, in which the tenor of sesquioxides bears no relation to that of clinoenstenite. Optic and chemical data seem to show that diopside (or augite) is miscible in all proportions with acmite,[13] while recent work indicates the existence of a similar series between diopside and jadeite,[14] and suggests one between acmite and hedenbergite[15] and another between acmite and jadeite.[16] There is no evidence at present to show that spodumenite is miscible in large amounts in any of the other monoclinic types. In summary, all types of monoclinic pyroxene (except spodumenite) are probably mutually miscible (*at high temperature or pressure*) in large, if not in all, proportions, and the entire group may be called pyroxene. Furthermore, limited amounts of $MnSiO_3$ (or $CaMnSi_2O_6$?) are soluble in diopside and hedenbergite, forming *schefferite*, and limited amounts of the same with $CaZnSi_2O_6$ (or

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[10] A. Lacroix: *Minéral. France*, IV, 1910, p. 765.

[11] N. L. Bowen: *Am. Jour. Sci.*, CLXXXVIII, 1914, p. 245. The existence of enstatite and augite side by side in some rocks shows that mix-crystals are not stable under all conditions and it may be suggested that instability is caused by formation of enstatite rather than clinoenstatite. According to Wyckoff (*Am. Jour. Sci.*, CCX, 1925, p. 383) X-ray study suggests that diopside and clinoenstatite " unmix " on cooling, and give two patterns.

[12] C. Doelter: *Handb. Mineralchemie*, II, 2, 1917, p. 556.

[13] For example: C. Doelter: *Handb. Mineralchemie*, II, 1, 1917, p. 556.

[14] H. S. Washington: *Proc. U. S. Nat. Mus.*, LX, 1922, pt. 14. Earlier work by Deleano (*Cent. Min.*, 1917, p. 290) indicates that this series is unstable at ordinary pressure and cannot be formed artificially.

[15] A. Lacroix: *Compt. Rend.*, CLXIII, 1916, p. 726.

[16] R. Doht and C. Hlawatsch: *Verh. Geol. Reichanst. Wien*, 1913, p. 79.

$ZnSiO_3$?) are soluble in the same minerals, forming *jeffersonite*. Diopside[17] is capable of dissolving less than 3 per cent $CaSiO_3$.

Triclinic pyroxenes include rhodonite and babingtonite, besides other less familiar types.[17a]

In tabular form the pyroxenes may be arranged as follows:

Species	Subspecies	*a* : *b* : *c*	β	Composition
		ORTHORHOMBIC		
Enstenite	Enstatite	1.0308 : 1 : 0.5885 *	90° 0′	$MgSiO_3$
	Hypersthene	1.0295 : 1 : 0.5868 *	90° 0′	$(Mg,Fe)SiO_3$
		MONOCLINIC		
Pyroxene	Clinoenstatite	1.033 : 1 : 0.591	......	$MgMgSi_2O_6$
	Clinohypersthene	....	......	$(Mg,Fe)_2Si_2O_6$
	Pigeonite	....	......	$m(Mg,Fe)_2Si_2O_6 \cdot nCaMgSi_2O_6$
	Diopside	1.0913 : 1 : 0.5895	74° 9′	$CaMgSi_2O_6$
	Hedenbergite	1.0912 : 1 : 0.5843	74° 35′	$CaFeSi_2O_6$
	Augite	1.092 : 1 : 0.589	74° 10′	$Ca(Mg,Fe)Si_2O_6$ with $MgSiO_3$ and $(Al,Fe)_2O_3$
	Aegirinaugite	....	......	Augite with $NaFeSi_2O_6$
	Acmite	1.099 : 1 : 0.601	73° 11′	$NaFeSi_2O_6$
	Jadeite	1.103 : 1 : 0.613	72° 44′	$NaAlSi_2O_6$
Spodumenite	....	1.124 : 1 : 0.636	69° 40′	$LiAlSi_2O_6$

TRICLINIC

Species	Subspecies	*a* : *b* : *c*	α	β	γ	Composition
Pyroxmangite	....	....	....	....	......	$(Fe,Mn)SiO_3$
Sobralite						$CaMgFe_2Mn_4(SiO_3)_8$?
Rhodonite	....	1.073 : 1 : 0.621	103° 18′	108° 44′	81° 39′	$CaMn_5(SiO_3)_6$?
	Fowlerite	....	....	....	......	$Ca(Mn,Fe,Zn)_5(SiO_3)_6$?
Vogtite (artif.)						$Ca(Fe,Mn)_2(SiO_3)_3$
Bustamite						$CaMnSi_2O_6$?
Babingtonite	....	1.069 : 1 : 0.631	104° 21′	108° 31′	83° 34′	$Ca(Fe,Mn)Si_2O_6$, etc.

* These axial ratios make the *a* axis longer than the *b* axis, contrary to the rule for orthorhombic crystals, but they thereby bring out the relation in form between the orthorhombic and the monoclinic pyroxenes.

It is to be noted that wollastonite ($CaSiO_3$) and pectolite ($HNaCaSi_2O_6$) are commonly included among the monoclinic pyroxenes to which they are certainly related, but they differ in axial ratio, in cleavage, and in optical orientation; they are therefore not here included among the pyroxenes.

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[17] Allen, *et al.*: *Am. Jour. Sci.*, CLXXVII, 1909, p. 19.

[17a] A. N. Winchell: *Am. Mineral.*, XII, 1927, p. 10.

ENSTATITE ORTHO. $a:b:c = 0.970:1:0.571$ $MgSiO_3$

COMP.—Natural enstatite free from iron is very rare; by some writers varieties containing less than 5 per cent FeO are called enstatite, from 5 to 14 per cent *bronzite*, and more than 14 per cent hypersthene. However, bronzite was originally applied to varieties containing inclusions which produced a bronzy luster. In petrography enstatite is commonly used for types which are positive and hypersthene for those which are negative. Enstatite and hypersthene may contain notable percentages of alumina and ferric iron; according to Washington [18] and Wherry [19] these are present merely as oxides, Al_2O_3 and Fe_2O_3, in augite, and presumably also in the orthorhombic pyroxenes.

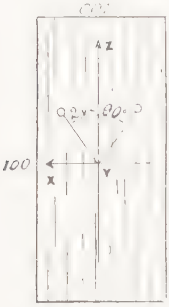

FIG. 90.—Optic orientation of enstatite.

PHYS. CHAR.—Crystals prismatic, rare; twinning rare, on 014 or 101. Distinct 110 cleavages at 88° 16′; parting on 010, less commonly 100, rarely 001. H. = 5.5. G. = 3.18. Insoluble in HCl.

OPT. PROP.—The plane of the optic axes is parallel to 010; the positive acute bisectrix is normal to 001. The optic angle about Z, the refringence and the birefringence increase with increase of iron, as shown in Fig. 91 and in the following data:

Properties	Enstatite			Hypersthene			
	Artificial	Moravia	Norway	Lauterbach	Labrador	Paul Island	Mt. Pelée
%FeO + MnO =	0.0	2.76	5.20	10.6	14.8	22.6	29.1
2V over Z =	31°	69° 42′	76° 54′	95°	.....	......	122°
N_g =	1.658	1.665	1.6715	.....	1.705	1.7270	
N_m =	1.653	1.659	1.6658	1.685	1.702		
N_p =	1.650	1.656	1.6607	.....	1.692	1.7158	
$N_g - N_p$ =	0.008	0.009	0.0108	.....	0.013	0.0112	
G. =	3.18	.....	3.27	3.34	3.40	......	3.54

Color white, gray, yellow, brown, olive green; the darker colors belong to varieties containing more iron (bronzite). Enstatite is colorless in this section; bronzite is colorless or nearly so, but in sections about 1 mm. thick it is pleochroic with X = pale yellow, Y = brownish yellow, Z = bright green.

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[18] H. S. Washington: *Am. Jour. Sci.*, CCIII, 1922, p. 117.

[19] E. T. Wherry: *Am. Mineral.*, VIII, 1923, p. 1.

Inver.—Pure magnesian enstatite is believed to be metastable, inverting to the stable form, clinoenstatite, at temperatures of about 1200° C. With a little iron present the temperature of inversion is lowered. On the other hand enstatite at ordinary pressure is probably more stable than the corresponding amphibole.

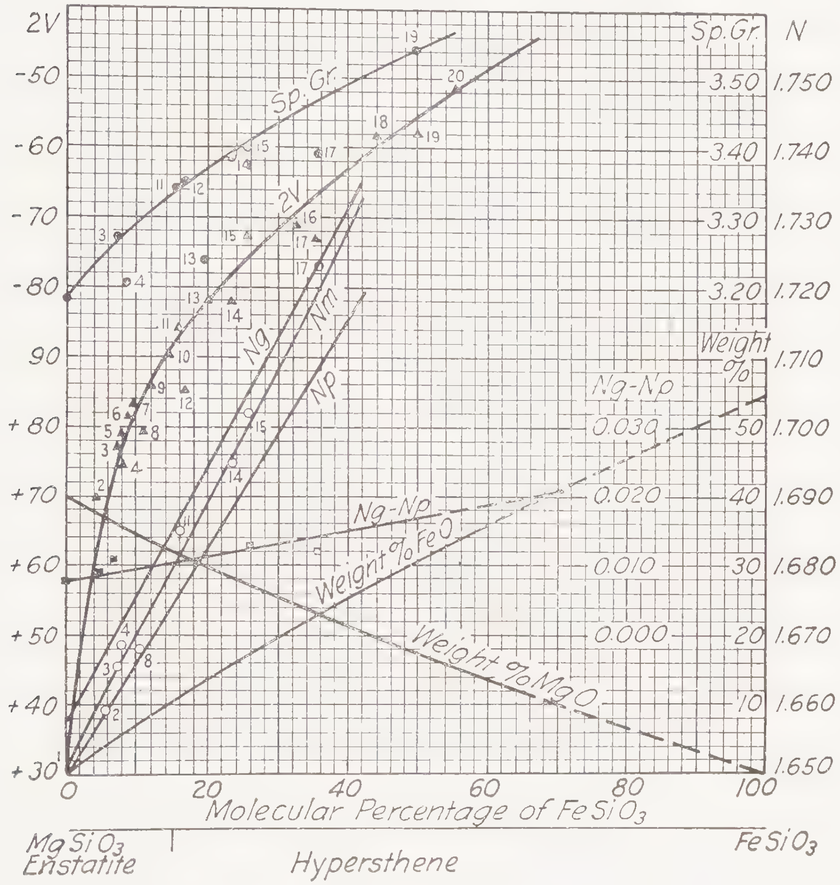

Fig. 91.—Variations of composition and optic properties in the enstenite series.

Incl.—Gaseous or liquid inclusions are not rare; they may be elongated parallel to the vertical axis of the pyroxene. Vitreous inclusions and inclusions of various other minerals, such as magnetite, apatite, quartz, etc., are found. Bronzite contains inclusions regularly arranged which give it a submetallic bronzy luster. See hypersthene for further description.

Alter.—Enstatite alters rather easily to a variety of antigorite called bastite, which is geometrically oriented on the original pyroxene, one crystal of bastite replacing one crystal of enstatite. The trace of the easy cleavage in vertical sections is in the same direction in enstatite and bastite, but in the former Z is parallel with the trace of the cleavage while in the latter Y occupies this position and the acute bisectrix $X(= a)$ is normal to the plane of the cleavage.

Enstatite is less commonly altered to *uralite* (a variety of hornblende) than are the monoclinic pyroxenes. The rarity of this type of alteration may be due to the absence or small tenor of alumina in enstatite. Still less commonly it alters to talc, or to antigorite other than bastite.

Occur.—Enstatite is a common constituent of many basic igneous rocks, as well as of serpentine derived from them. It is also found in rocks produced by contact endomorphism, and in some crystalline schists. Finally, it is an important constituent of many meteorites.

Diag.—Enstatite is distinguished from hypersthene by difference in optic sign, and by very little or no color and pleochroism, as well as by lower refringence; it differs from monoclinic pyroxenes in showing parallel extinction in vertical sections, and in other characters resulting from orthorhombic symmetry.

HYPERSTHENE Orth. $a : b : c = 1.0295 : 1 : 0.5868$ $(Mg,Fe)SiO_3$

Comp.—See enstatite.

Phys. Char.—Crystals prismatic, slightly elongated vertically or tabular parallel to 100 or 010. Usually lamellar or granular massive. Twinning rare on 101. Distinct 110 cleavage. Good 010 (rarely 100) parting. H. = 5–6. G. = 3.3–3.5. F. = 5 to black enamel. Partly decomposed by HCl.

Opt. Prop.—The optic plane is parallel to 010; the negative acute bisectrix is normal to 100. The optic angle about Z, the refringence and the birefringence increase with increase of iron as shown in Fig. 91, and the data given under enstatite. Dispersion $\rho > v$, weak.

Color dark brown, grayish black, yellowish brown. Luster often submetallic and bronze-like on 010 (*bronzite* variety). In thin section clear reddish or greenish with distinct pleochroism, the intensity increasing with the tenor of iron. The following are examples of pleochroism:

X =	clear red	reddish yellow	brownish red	hyacinth red
Y =	yellowish brown	pale yellow	clear red	straw yellow
Z =	clear green	pale green	bottle green	sky blue

β-Hypersthene is an abnormal type[10] in which the optic plane is parallel to 001 and the elongation is ±; the optic angle is large. A zone containing the normal and abnormal hypersthene is uniaxial. Found in basic volcanic rocks. Very rare.

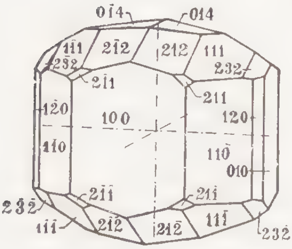

Fig. 92.—A crystal habit of hypersthene.

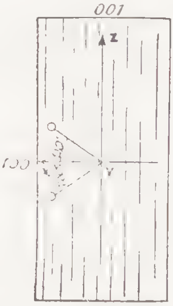

Fig. 93.—Optic orientation of hypersthene.

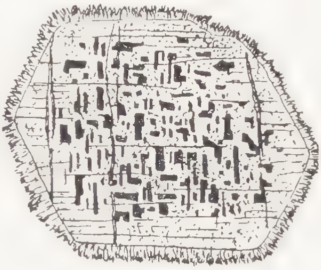

Fig. 94.—Schiller inclusions in hypersthene (bronzite). (After Lacroix.)

Occur.—Hypersthene with plagioclase makes up a large part of some basic plutonic rocks, notably norites. It is also abundant in some andesites, less common in peridotites and pyroxenites; it is not rare in meteorites.

Diag.—See enstatite.

CLINOENSTATITE Mono. $a : b : c = 1.033 : 1 : 0.591$ $\beta = 87° 26'$ $MgSiO_3$

Phys. Char.—Crystals 100 tablets, or prismatic, vertically elongated. Good 110 cleavages at 88° 8′. Constant twinning on 100. H. = 6. G. = 3.19. Begins to dissociate to Mg_2SiO_4 and SiO_2 at 1557° C. and fusion is complete at 1577° C.; insoluble in HCl.

Opt. Prop.—The plane of the optic axes is normal to 010; in pure $MgSiO_3$ the acute bisectrix Z makes an angle of 22° with *c* in the obtuse angle β; the optic angle (2V) is $53\frac{1}{2}°$ with slight dispersion and $N_g = 1.660$, $N_m = 1.654$, $N_p = 1.651$, $N_g - N_p = 0.009$.

Colorless, yellowish, etc. The color deepens with increase of iron content. Colorless in thin section.

Occur.—The pure magnesian type is quite rare in igneous rocks and in meteorites; types with little iron are known in certain diabases and are not extremely rare in stony meteorites.

DIAG.—Characterized by lamellar twinning on 100 and an extinction angle of 22° on 010. This angle increases as the mineral varies toward clinohypersthene.

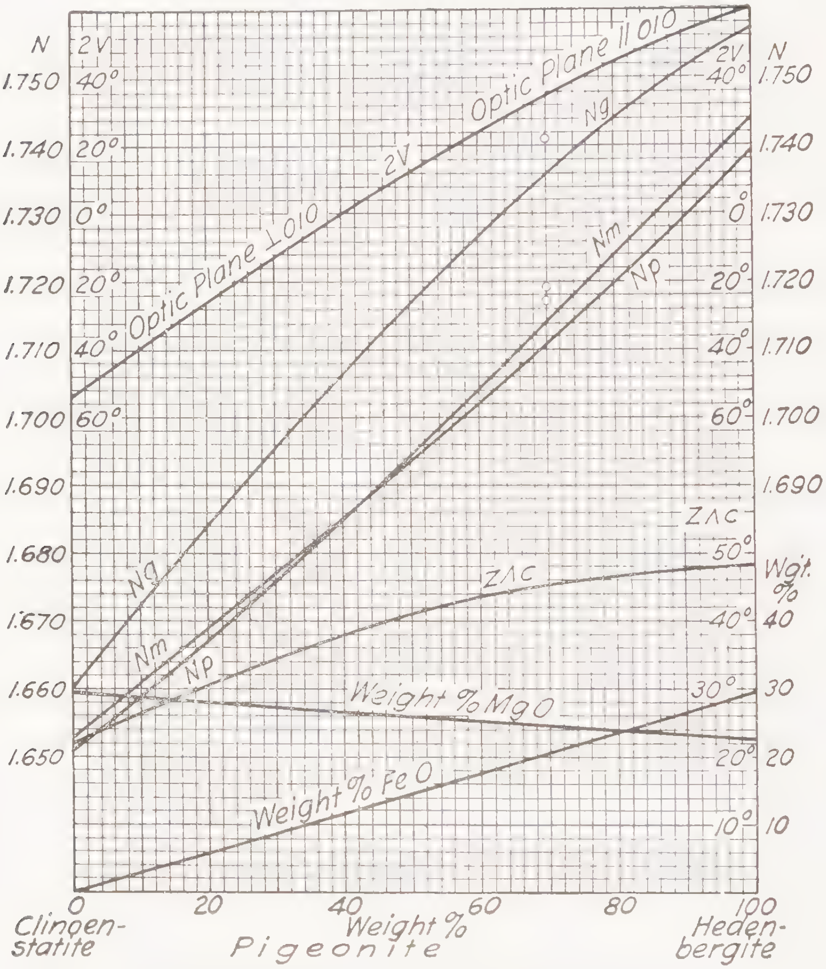

FIG. 95.—Variations in composition and optic properties in the clinoenstatite-hedenbergite series.

CLINOHYPERSTHENE MONOCLINIC $(Mg,Fe)SiO_3$

COMP.—By gradual replacement of magnesium by iron clinoenstatite grades into clinohypersthene, but there is no change of sign in this series, and therefore the subspecies must be divided arbitrarily; by analogy with enstenite 12 per cent FeO may be a desirable limit.

PHYS. CHAR.—Crystals prismatic, elongated parallel to *c*. Lamellar twinning on 100 characteristic. Good 110 cleavages. H. = 6. G. = 3.4 ±. F. = 5. Partly decomposed by HCl.

OPT. PROP.—The optic plane is normal to 010. The acute bisectrix Z makes an angle[20] of 29° with *c* in the obtuse angle β; the optic angle is large, but not accurately known. The refringence and birefringence have not been measured, but are very similar[20] to those of hypersthene. By graphic solution based on the properties of pure diopside, pure clinoenstatite, and a uniaxial pyroxene (pigeonite) from Mull[21] with 27.77 FeO containing about 78 per cent of clinohypersthene and 15 per cent of diopside (pure) clinohypersthene with Fe : Mg = 1 : 1 (by weight) would have: (+) $2V = 30°$, $Z \wedge c = 46°$, $N_g = 1.73$, $N_m = 1.715$, $N_p = 1.713$, $N_g - N_p = 0.017$ (see Fig. 100).

Color brown; colorless or weakly pleochroic in thin section.

OCCUR.—Unknown in igneous rocks, but found in some meteorites.

DIAG.—Characterized by lamellar twinning on 100 and an extinction angle of 29° on 010. This angle decreases with decrease of iron to 22° in clinoenstatite.

PIGEONITE MONOCLINIC $m(Mg,Fe)SiO_3 \cdot nCaMgSi_2O_6$

COMP.—There is a continuous series from clinoenstatite to diopside and probably from all types of *clinoenstenite* to all types of the diopside-hedenbergite series. That portion of this double series characterized by a small optic angle has been named pigeonite.[22] These types are probably only metastable at ordinary temperatures.

PHYS. CHAR.—Crystals similar to those of diopside; lamellar twinning on 100 not uncommon. Distinct 110 cleavages; good parting parallel to 001 or 100. H. = 6. G. = 3.2–3.4. F. = 4–5. Insoluble or slightly attacked by HCl.

OPT. PROP.—The optic plane is normal to 010 in pigeonite very low in calcium and parallel to 010 in pigeonite with about 7–10 per cent CaO.

In pigeonite with the optic plane parallel to 010 the dispersion is inclined with $\rho > v$, and in pigeonite with the optic plane normal to 010 the dispersion is horizontal with $\rho < v$; the dispersion increases with the tenor of iron, being very weak in the absence of iron.

The sign is positive in all cases, and the optic angle is small and conspicuously variable; it may even vary in a single crystal. The acute bisectrix Z makes an angle of 22° to 45° with c in the obtuse angle β, the angle decreasing with decrease of lime. These variations are illustrated in the following data, in Fig. 96, and also in Fig. 100, which shows the variations in the clinoenstenite-diopside-hedenbergite system.

Aland Islands[23]	Onega Sea, Finland[24]	Island of Mull[25]
$2V = 15°–20°$	$2V = 23°–40°$	$2V = 0°$
$N_g = 1.711$	$N_g = 1.741$	$N_g = 1.744$
$N_m = 1.691$	$N_m = 1.719$	$N_m = 1.714$
$N_p = 1.690$	$N_p = 1.717$	$N_p = 1.714$
$N_g - N_p = 0.021$	$N_g - N_p = 0.024$	$N_g - N_p = 0.030$
$Z \wedge c = 44°$	$Z \wedge c = 45°$	$Z \wedge c = 40° \pm$
G. = 3.42	G. = 3.46	G. = 3.42

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[20] A. Lacroix: *Bull. Soc. Sc. Nat. Ouest.*, VI, 1906, p. 94.

[21] A. F. Hallimond: *Mineral Mag.*, XVII, 1914, p. 97.

[22] A. Lacroix: *Minéral. France*, IV, 1910, p. 767; A. N. Winchell: *Am. Geol.*, XXVI, 1900, p. 199.

[23] W. Wahl: *Tsch. Min. Pet. Mit.*, XXVI, 1907, p. 18. $SiO_2 = 51.30$, $TiO_2 = 0.72$, $Al_2O_3 = 2.36$, $Fe_2O_3 = 2.22$, $FeO = 18.83$, $MgO = 16.56$, $MnO = 0.57$, $NiO = 0.05$, $CaO = 6.96$, $Na_2O = 0.21$, $K_2O = 0.37$, $H_2O = 1.00$, total = 101.15.

[24] W. Wahl: *Op. cit.*, p. 27. $SiO_2 = 50.36$, $TiO_2 = 0.80$, $Al_2O_3 = 2.40$, $Fe_2O_3 = 2.35$, $FeO = 18.15$, $MnO = 0.56$, $NiO = 0.04$, $MgO = 11.37$, $CaO = 13.97$, $Na_2O = 0.26$, $K_2O = 0.19$, $H_2O = 0.55$, total = 101.09.

[25] A. F. Hallimond: *Min. Mag.*, XVII, 1914, p. 97. $SiO_2 = 49.72$, $TiO_2 = 0.85$, $Al_2O_3 = 0.90$, $Fe_2O_3 = 1.72$, $FeO = 27.77$, $MnO = 0.98$, $MgO = 12.69$, $CaO = 3.80$, $Na_2O = 0.23$, $K_2O = 0.12$, $H_2O = 1.35$, total = 100.13.

Color white, brownish, greenish, black. In section colorless or weakly pleochroic with X = yellowish green, Y = brownish pink, Z = greenish white in the mineral from Aland Island, X = Y = smoky brown, Z = pale yellow in that from Mull, and X = pink or flesh colored, Y = pale yellowish green, Z = pale green in that from Pigeon Point, Minn.[26]

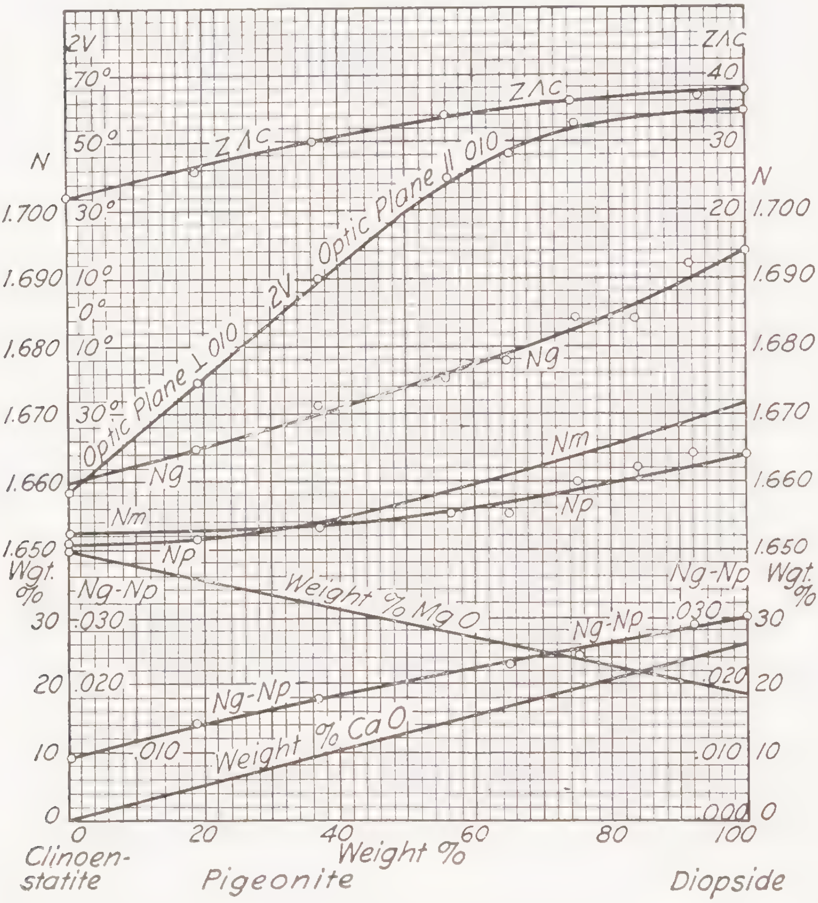

Fig. 96.—Variations in composition and optic properties in the clinoenstatite-diopside series.

Alter.—Changes to serpentine very easily; other modes of alteration are similar to those of augite.

Occur.—Not rare in diabase and found in basalt, gabbro, etc., in many parts of the world.

Diag.—The small optic angle is quite distinctive for this type of pyroxene.

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[26] A. N. Winchell: *Am. Geol.*, XXVI, 1900, p. 199.

DIOPSIDE — MONOCLINIC — $CaMgSi_2O_6$

$\updownarrow$ $a:b:c = 1.0913:1:0.5895 \quad \beta = 74° 9'$ $\updownarrow$

HEDENBERGITE — MONOCLINIC — $CaFeSi_2O_6$

$a:b:c = 1.0913:1:0.5843 \quad \beta = 74° 35'$

PHYS. CHAR.—Crystals commonly short prisms with 100 and 010 or with 111 and the pinacoids absent or present. Twinning common on 100 or 001, either simple or lamellar and then giving parting; basal lamellar twinning and parting can be produced by strain. Cleavage always distinct parallel to 110 at an angle of 87°. Parting on 100 well developed in the variety *diallage*; also on 001. H. = 5-6. G. = 3.275 (pure diopside) to about 3.55 (hedenbergite). F. = 1391° C. (pure diopside); less with iron. Insoluble in HCl; only slowly soluble in HF, but much more easily than enstenite.

OPT. PROP.—The plane of the optic axes is parallel to 010, and the positive acute bisectrix Z makes an angle with the vertical axis *c* in the obtuse angle β which varies from 38.5° in pure diopside to 48° in pure hedenbergite. The mean index of refraction increases from 1.676 in diopside to about 1.75 in hedenbergite, but the birefringence decreases in the same range from 0.030 to 0.018. There is remarkably little change in the optic axial angle. These relations are shown in the following table and also in Fig. 99. In ferriferous types the inclined dispersion is distinct with $\rho > v$, and the extinction angle ($Z \wedge c$) is greater (by 6′ to 12′) for red than for violet.

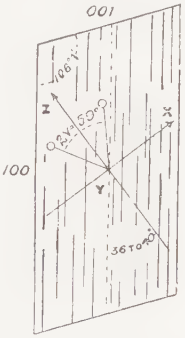

FIG. 97.—Optic orientation of diopside.

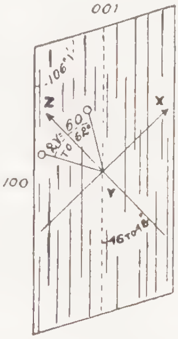

FIG. 98.—Optic orientation of hedenbergite.

	Diopside		Salite	Hedenbergite	
% FeO =	0.0	2.9	17.5	20.3	29.4
% MgO =	18.5	16.4	6.9	1.7	0.0
(+) 2V =	59.3°	59°	60°	59° 52′	60°
N_g =	1.694	1.6996	......	1.7506	1.757
N_m =	1.6715	1.6776	1.7163	1.7366	1.745
N_p =	1.664	1.6707	......	1.7320	1.739
$N_g - N_p$ =	0.030	0.0289	......	0.0186	0.018
$Z \wedge c$ =	38.5°	38° 42′	45°	47° 10′	48°

$N'_g - N'_p$ on 110 = 0.022 in diopside and 0.011 in hedenbergite.

The optic data of the last column are derived from the graph, Fig. 99.

Color green, from nearly colorless to greenish black; also brown

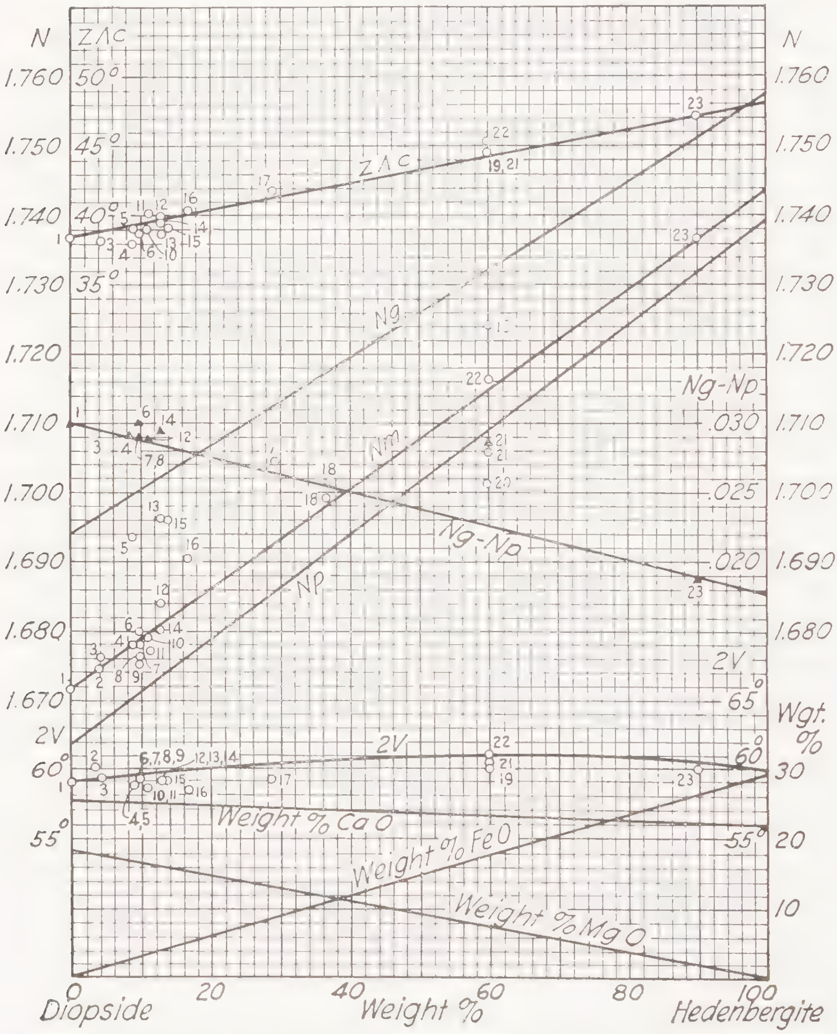

FIG. 99.—Variations of composition and optic properties in the diopside-hedenbergite system.

(diallage); in thin section color and pleochroism lacking except in ferrous types in which are found:

Ferriferous diallage	Hedenbergite
X = greenish	X = pale green
Y = brownish or reddish brown	Y = yellowish green
Z = greenish	Z = dark green

Incl.—Gaseous, liquid and vitreous inclusions sometimes arranged in zones. Some diallage has inclusions wholly like those of bronzite giving a bronze-like color and luster.

Alter.—Diopside alters in many different ways; one of the commonest is the change to antigorite, or to an aggregate of antigorite and chlorite, which often contains calcite and quartz, as well as grains of epidote. Another common alteration product is actinolite (or hornblende). This may be produced either by the alteration of one crystal of diopside to a single crystal of actinolite, or to a fibrous mass of amphibole. It may begin by alteration around the periphery or by attacking the diopside along cleavage lines. The green diopside of eclogite (called *omphacite*) alters similarly to a dark green hornblende called *smaragdite.* Other alteration products include biotite, feldspar, talc, opal, etc. When fused and recrystallized in nature augite usually results, sometimes with olivine and magnetite.

Occur.—Diopside is an important constituent of some igneous rocks, such as some pyroxene granites, diorites, syenites, pyroxenites, etc., but it is more important in some metamorphic rocks, especially contact types; it is also found in some schists. Finally, it is sparsely present in some meteorites, and in certain types of slag. Hedenbergite is very rare, being found only in ore deposits and contact rocks.

Varieties.—Besides the end compounds, diopside and hedenbergite, and the intermediate type *salite,* a variety containing 6 to 10 per cent MnO is known as *schefferite*; in it the angle between Z and *c* varies from 44° (in manganiferous diopside with 12.2 MnO + FeO) to 60° and more (with 20–25 MnO + FeO), and the pleochroism is weak in reddish yellow and brown tints; a variety containing 7 to 10 per cent MnO and 3 to 10 per cent ZnO is called *jeffersonite*;[27] in it the angle between Z and *c* reaches 54° and the optic angle is large. *Malacolite* is a variety with well-developed basal parting. *Diallage* is a type with parting parallel to 100 (or rarely 010); it may contain alumina and is then a variety of augite. *Chrome diopside* contains Cr_2O_3 (1–3 per cent) and some Al_2O_3 (1–7 per cent); it is emerald green in color. *Omphacite* is a variety often containing Al_2O_3 (5–9 per cent), having a green color, and occurring in eclogites. These last varieties emphasize the gradual natural gradation from diopside to augite.

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[27] A crystal with CaO = 23.7, MgO = 12.6, MnO = 7.4, and ZnO = 3.3 has G. = 3.39, (+) 2V = rather large, $\rho > v$ perceptible, $N_g = 1.710$, $N_m = 1.690$, $N_p = 1.682$, $N_g - N_p = 0.028$; another crystal with about 10 per cent each of FeO, ZnO, and MnO has G. = 3.5, (+) 2V = medium large, $N_g = 1.748$, $N_m = 1.731$, $N_p = 1.720$, $N_g - N_p = 0.028$; dark green in section, according to Larsen: *U. S. Geol. Surv. Bull.* 679, 1921.

Diag.—Not easily distinguished optically from augite which differs in containing sesquioxides; however, diopside has less dispersion and therefore better extinction in white light than most augite; the birefringence of pure diopside is greater than that of augite, but that of hedenbergite is less. Diopside differs from clinoenstatite and clinohypersthene in the position of the optic plane and from these and acmite and spodumenite in the extinction angle in the vertical zone. Pigeonite has a small optic angle. Jadeite is always fibrous, and contains abundant sodium.

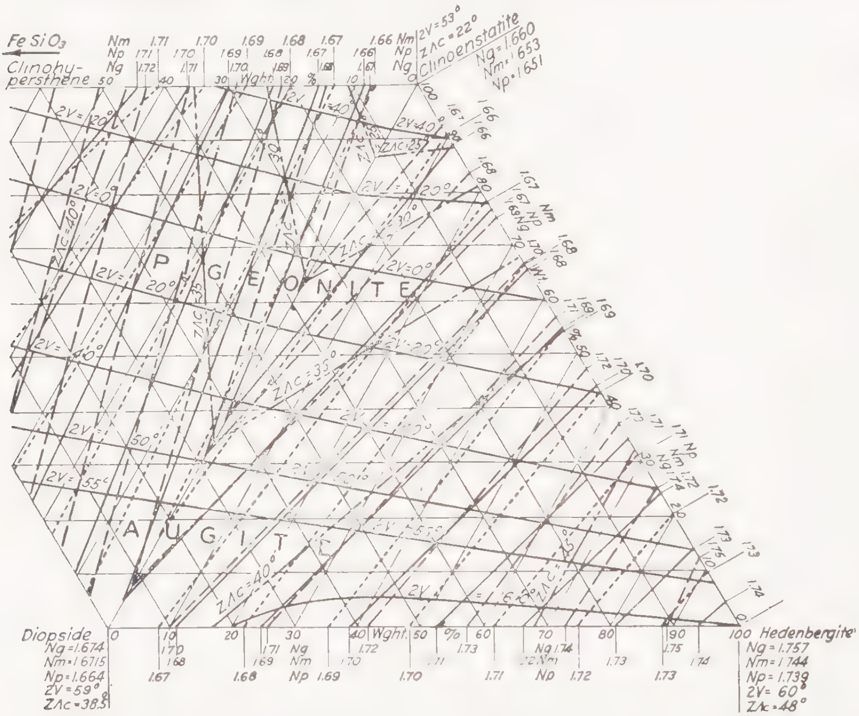


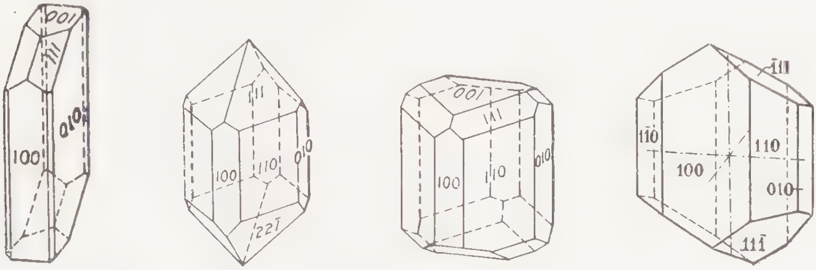
Fig. 100.—Variations of composition and optic properties in the clinoenstenite-diopside-hedenbergite system.

AUGITE Monoclinic $Ca)Mg,Fe)Si_2O_6$

$a : b : c = 1.902 : 1 : 0.584$ with $MgSiO_3$

$\beta = 47°10'$ and $(Al,Fe)_2O_3$

Phys. Char.—Crystals usually short thick prisms with 100 and 010, terminated by 111 or 001. Lamellar twinning on 100 common, giving distinct parting; also less commonly on 001 with parting which can be produced artificially. Simple twinning on 100 or 101; rare simple or cruciform twinning on $\bar{1}22$ or 011. Distinct 110 cleavages at 87°. H. = 5–6. G. = 3.2–3.6. F. = 3 ±. Only very slowly



FIGS. 101–104.—Crystal habits of augite.

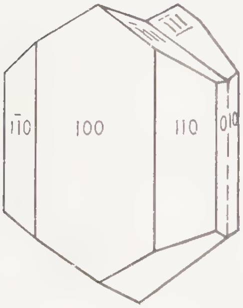


FIG. 105.—Simple twinning on 100 in augite.

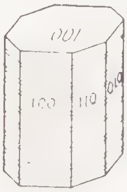


FIG. 106.—Lamellar twinning on 001 in augite.

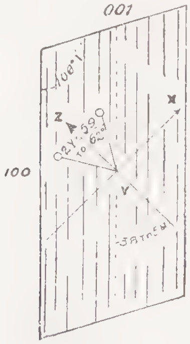


FIG. 107.—Optic orientation of augite.

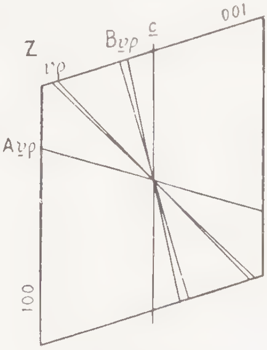


FIG. 108.—Dispersion in augite from Renfrew, Canada.

attacked by HCl (but titanaugite is completely soluble); much more rapidly attacked by HF than enstenite.

OPT. PROP.—The plane of the optic axes is parallel to 010 and the positive acute bisectrix Z makes an angle with *c* (trace of the cleavages in vertical sections showing only one direction of cleavage) of 38° to 54°. From all the data now available it appears that TiO_2, Al_2O_3 and Fe_2O_3 cause a distinct increase[28] in this extinction angle as compared with the angle of corresponding pyroxenes free of these oxides (whose properties are shown in Fig. 100). For example, the augite from Nishigatake, Japan[29] should have an extinction angle of 38°, if free from these oxides (as shown by plotting in Fig. 100); it has 0.58 TiO_2, 5.24 Al_2O_3 and 2.02 Fe_2O_3, and the extinction angle is 41.6°. Similar comparisons show that these oxides produce small increases (about .01 or .02 in ordinary cases) in the refringence, but a slight decrease in the birefringence. The angle of the optic axes is changed very little by them, but is increased decidedly by alkalies. The axial dispersion is weak with $\rho > v$; inclined dispersion is distinct, the extinction angle being about 1° less for red than for blue. It follows that in augite the optic axis nearly parallel with c shows more dispersion than the other; in all members of the diopside-hedenbergite-clinoenstenite system the reverse condition is reported. The following data were obtained recently on analyzed crystals.

	Nishigatake[29]	Stromboli[30]	Renfrew[31]	Haleakala[19]
(+) 2V =	58° 25′	57° 59′	61° 12′	58° (red) 62° (blue)
N_g =	1.7105	1.719	1.7227	1.724
N_m =	1.6917	1.699	1.7039	1.706
N_p =	1.6859	1.693	1.6975	1.700
$N_g - N_p$ =	0.0246	0.026	0.0252	0.024
$Z \wedge c$ =	41° 36′	43° 20′	44° 53′	47° (red) 49° (blue)

$N'_g - N'_p$ on the prismatic cleavage is about 0.012 to 0.015.

Color green to black, brown to black, rarely grayish green or yellow. In thin section color and pleochroism usually absent or very weak; when rich in iron or titanium pleochroism is distinct, as follows:

	Ferriferous augite	Titaniferous augite
X =	greenish	greenish yellow or reddish
Y =	brownish to reddish brown	red or violet
Z =	greenish	greenish yellow, reddish or violet

When sodium is present in important amounts the mineral grades into aegirinaugite which is decidedly green.

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[28] Artificial diopside with about 15 per cent Al_2O_3 has $Z \wedge c = 41°$ (Deleano: *Cent. Min.*, 1917, p. 290); with about 15 per cent Fe_2O_3 diopside has $Z \wedge c = 45°$; diopside with both Al_2O_3 and Fe_2O_3 (about 10 per cent of each) is unstable in slags.

[29] R. Ohashi: *Mineral. Mag.*, XIX, 1921, p. 173.

[30] S. Kozu and H. S. Washington: *Am. Jour. Sci.*, CXCV, 1918, p. 463.

[31] E. A. Wülfing: *Tsch. Min. Pet. Mit.*, XV, 1895, p. 29.

Incl. Gaseous, liquid and vitreous inclusions occur irregularly or arranged in zones. Diallage may have inclusions wholly like those of bronzite.

Alter.—Augite has many different alteration products; the commonest is probably uralite or secondary hornblende. This may develop so that a single crystal of uralite replaces a single crystal of augite, or the latter may yield a fibrous aggregate of uralite, sometimes with feldspar. The alteration may begin around the periphery or it may proceed along cleavages. Another common alteration product is antigorite, which may be fibrous or lamellar. Still another is biotite, which may alter further to chlorite, or the augite may change directly to chlorite; in such cases calcite, quartz, and epidote may be formed at the same time. In rare cases augite is changed to, or replaced by, quartz or calcite. By fumarolic action it may be changed to opal and quartz. When fused and recrystallized in nature, augite usually forms again, sometimes with olivine and magnetite.

Varieties.—Light colored varieties of augite which contain very little iron are known as *leucaugite* and resemble diopside very closely, but the extinction angle is greater (40° to 45°) and the extinction angle for red is less than for blue light. *Ferriferous augite* is dark colored and pleochroic, as already noted; the extinction angle is about 45° to 54°; the dispersion is distinct with $\rho < v$, and the extinction angle is distinctly less for red than for blue, resulting in incomplete extinction in clinopinacoid sections. *Titaniferous augite* has a peculiar reddish or violet color and pleochroism as noted; otherwise its properties are like those of ferriferous augite, the dispersion being even greater. *Diallage* is characterized by abundant parting parallel to 100; it grades into a variety of diopside. *Omphacite* is a green variety of augite or diopside found in eclogite.

Occur.—Augite is especially abundant in igneous rocks and diopside in contacts and schists, but neither is confined to such occurrences. Augite is found in most of the common igneous rocks and is

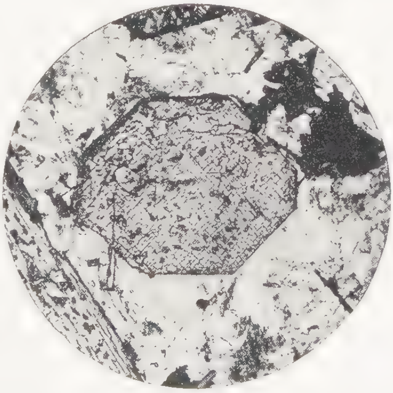
Fig. 109.—Photomicrograph of augite in thin section.

abundant in several of them; it is also found in various metamorphic rocks, including some schists. It is known, but not common in slags and in meteorites.

Diag.—Augite differs from the diopside-hedenbergite-clinoenstenite system in containing appreciable amounts of alumina or ferric iron or both. It also has more dispersion than the latter, which may prevent complete extinction or give visible effects in the optic axis nearly parallel to *c*. Further, the extinction angle in common diopside is about 40°, while in augite it is nearly always more than 40° and may be 48°–54°. Finally, the extinction angle in augite is less for red than for blue, while the reverse condition is found in diopside. Augite differs decidedly in extinction angle from aegirinaugite, acmite and spodumenite, while jadeite is always fibrous and contains abundant sodium.

AEGIRINAUGITE Monoclinic Augite with $NaFeSi_2O_6$

Phys. Char.—Crystals short prismatic with 100 prominent; twinning on 100 common. Distinct 110 cleavages at 87°. H. = 5–6. G. = 3.5.

Opt. Prop.—The optic plane is parallel to 010; the axis Z makes an angle of 54° to 85° with *c*; the optic angle about Z varies from about 75° to 100° or more. In the typical case containing about equal amounts of diopside and acmite molecules $2V = 90° \pm$ and $Z \wedge c = 60°$ to 70°. Strong inclined dispersion which may cause incomplete extinction in white light. There is a complete gradation from diopside and augite to acmite through aegirinaugite, but intermediate types are uncommon and perhaps only stable at high temperature. Lacroix[15] has described an acmite-hedenbergite from Madagascar.

	Italy[32]	Langban[33]	Montana[34]
$NaFeSi_2O_6\% =$	14.8	?	42.5
$(+)\ 2V =$	60°	65°	Large
$N_g =$	1.709	1.710	1.747
$N_m =$	1.687	1.688	
$N_p =$	1.680	1.679	1.720
$N_g - N_p =$	0.029	0.031	0.027
$Z \wedge c =$	65°-75°	70°	66°

Color dark green to greenish black. In thin section green with strong pleochroism, as follows:

	Italy	Montana	Alkaline rocks
X =	olive green	light green	grass green
Y =	olive green	greenish yellow	clear green
Z =	yellow	pale yellow	yellowish to brownish

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[32] C. Viola: *Neues Jahrb. Min.*, 1899, I, p. 101. Also E. H. Kraus: *Zt. Kr.*, XXXIII, 1900, p. 36 (and 53).

[33] The so-called "*urbanite*," differing from aegirinaugite in the absence of Al_2O_3. The optic measurements were made by Larsen (*U. S. Geol. Surv. Bull.* 679, 1921, p. 225) not on analyzed crystals. The analysis quoted by Sjögren (*Bull. Geol. Inst. U. Upsala*, II, 1894, p. 77) seems too high in Na_2O and Fe_2O_3 to correspond with the optic data.

[34] E. S. Larsen and W. F. Hunt: *Am. Jour. Sci.*; CLXXXVI, 1913, p. 295. Contains 35.0 $CaMgSi_2O_6$, 14.1 $CaFeSi_2O_6$ and 5.5 $NaAlSi_2O_6$; 2.86 V_2O_3 calculated with Fe_2O_3 in acmite.

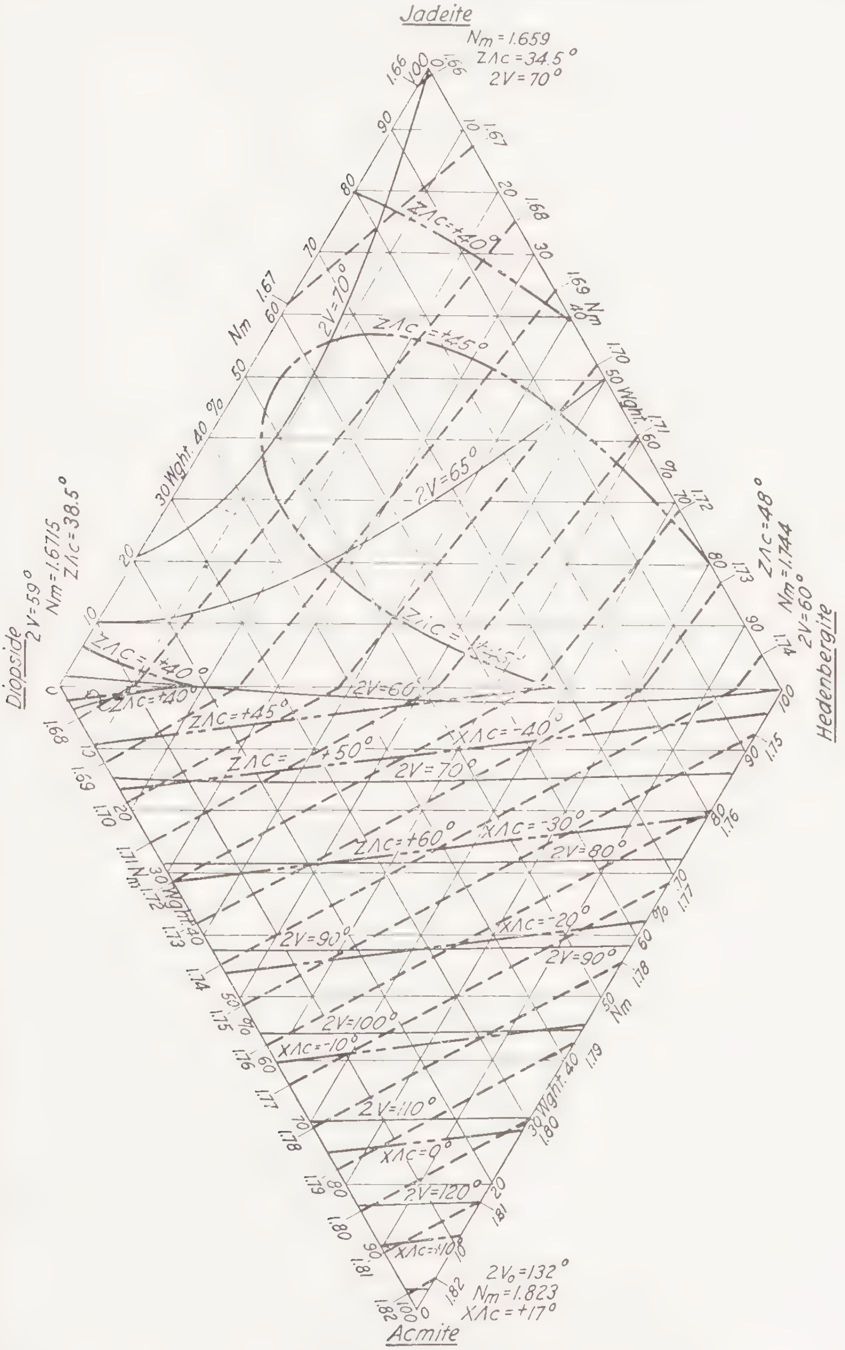

FIG. 110.—Variations in composition and optic properties in the acmite-diopside-jadeite-hedenbergite system. Based on insufficient data and therefore not accurate.

Occur.—Common in nephelite syenite, phonolite and many alkaline igneous rocks, in which it may be present with, or take the place of, augite.

Diag.—Differs from augite in color and pleochroism as well as in extinction angle and optic angle, and from acmite in extinction angle and optic angle.

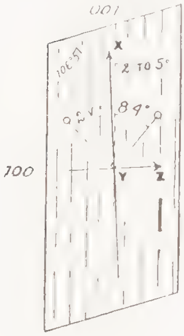

Fig. 111.—Optic orientation of acmite.

ACMITE (*Aegirite*) Monoclinic $NaFeSi_2O_6$

$a : b : c = 1.099 : 1 : 0.601 \quad \beta = 73° 11'$

Phys. Char.—Crystals long prismatic, vertically striated, with terminations which are acute in *acmite* and obtuse in aegirite. Twinning on 100. Perfect 110 cleavages at 88°; parting on 010 or 001. H. = 6–6.5. G. = 3.5–3.55. F. = 2 (940° to 970°) to black magnetic globule. Only slightly attacked by acids.

Opt. Prop.—The optic plane is parallel to 010; the negative acute bisectrix X makes a small angle (about 5°) with c in the obtuse angle β; that is $Z \wedge c = +95°$. The optic angle is large with $\rho > v$ and distinct inclined dispersion, the extinction angle for red being less than that for blue, producing incomplete extinction in white light in 010 sections. The birefringence is strong.

	Kola [35]	Libby, Mont. [36]	Langesund [37]	Calculated [38]	Artificial [38a]
$NaFeSi_2O_6\%$ =	60.7	74.4	75.5	100.0	100.0
$(-)\ 2V$ =	66°	69°	62° 13′	48°	60°
N_g =	......	1.782	1.8126	1.834	1.836
N_m =	1.801	1.770	1.7990	1.823	1.816
N_p =	1.777	1.745	1.7630	1.776	1.776
$N_g - N_p$ =	......	0.037	0.0496	0.058	0.060
$X \wedge c$ =	4° to 5°	− 1.4°	+ 4°	+ 17°	+ 8°

Color of acmite reddish brown to black and of aegirite green to black. In thin section brown or green with strong pleochroism and absorption $X > Y > Z$.

	Kola	Libby, Mont.	Langesund	Ditro
X =	clear green	dark brown	deep olive to grass green	dark brown
Y =	yellowish green	clear brown	olive to grass green	brownish green
Z =	brownish yellow	pale yellowish brown	yellow	brownish green

According to Washington and Merwin,[39] acmite may be yellow in thin section, with little or no pleochroism; or may even be colorless. A colorless variety from Hawaii has $N_g = 1.81$, $N_p = 1.75$, $N_g - N_p = 0.06$.

Occur.—In alkaline igneous rocks including nephelite syenite, phonolite, syenite pegmatite, etc.

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[35] W. Ramsay: *Fennia*, III, No. 7, p. 40. The optic data and tenor of Na_2O suggest that iron reported as FeO should be Fe_2O_3; then the tenor of $NaFeSi_2O_6$ would be 90.0.

[36] E. S. Larsen and W. F. Hunt: *Am. Jour. Sci.*, CLXXXVI, 1913, p. 289; with 3.98 V_2O_3 calculated with Fe_2O_3 for acmite.

[37] E. A. Wülfing: *Zeit. Kryst.*, XXIII, 1894, p. 297. Analysis by C. Doelter: *Tsch. Min. Pet. Mit.*, I; 1878, p. 376.

[38] On basis of No. 3 and data for hedenbergite and pure diopside (graphic solution).

[38a] H. S. Washington and H. E. Merwin: *Am. Mineral.*, XII, 1927, p. 233.

[39] *Amer. Jour. Sci.*, CCVI, 1923, p. 107.

DIAG.—Distinguished from other monoclinic pyroxenes by the small extinction angle, the negative sign and negative elongation, the strong birefringence, and the deep color and pleochroism; further, the density is greater and the fusibility is lower.

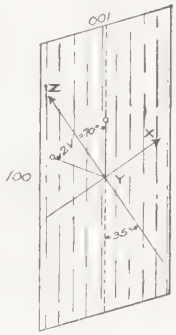

FIG. 112.—Optic orientation of jadeite.

JADEITE MONO. $a : b : c = 1.103 : 1 : 0.613$ $NaAlSi_2O_6$
$\beta = 72° 44'$

PHYS. CHAR.—Crystals quite rare; usually in fibrous interlaced masses. Distinct 110 cleavages at 87°. Indistinct 100 parting. H. = 6–7. Very tenacious. G. = 3.3–3.5. F. = about 1060° C. Insoluble in acids.

OPT. PROP.—The optic plane is parallel to 010; the positive acute bisectrix Z makes an angle with c of 30° to 35° in the obtuse angle β. The optic angle is large with $\rho < v$; inclined dispersion weak.

	Thibet[40]	Burma[41]	Jadeite-diopside[42]		Jadeite-acmite[16]
$NaAlSi_2O_6\%$ =	95.7	89.8	47.0	28.5	32.5
(+) 2V =	70°±	71° 56′	70°–80°	.....	
N_g =	1.667	......	1.688	1.693	1.775
N_m =	1.659	1.654	1.674		
N_p =	1.655	......	1.666	1.665	1.735
$N_g - N_p$ =	0.012	......	0.022	0.028	0.04
$Z \wedge c$ =	34.5°	33° 34′	43°–47°	.....	40°

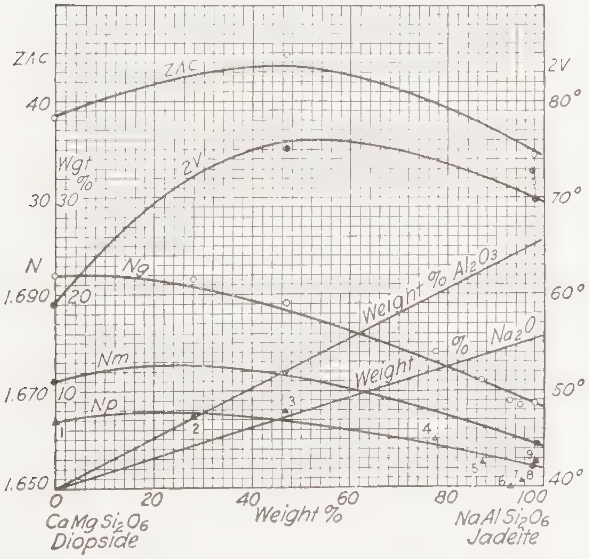

FIG. 113.—Variations in composition and optic properties in the diopside-jadeite series.

Color apple to emerald green, greenish white. Colorless in thin section.

Chloromelanite is a ferriferous jadeite related to jadeite-acmite; it commonly contains jadeite, acmite and diopside molecules in large amounts. It alters to smaragdite.

OCCUR.—In Burma, Thibet, France, Mexico, etc., in certain metamorphic rocks. Rare. Prehistoric man used both jadeite and chloromelanite, as well as nephrite, in making images, utensils, etc.

DIAG.—Differs from augite and diopside in its larger optic angle, smaller extinction angle, fibrous habit and mode of occurrence. It differs from acmite in its larger extinction angle, positive elongation and optic character, and fibrous habit.

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[40] H. S. Washington: *Proc. U. S. Nat. Mus.*, LX, 1922, pt. 14.

[41] J. Krenner: *Zeit. Kryst.*, XXXI, 1899, p. 502.

[42] H. S. Washington: *Loc. cit.* and *Jour. Wash. Acad. Sci.*, XII, 1922, p. 387.

SPODUMENITE (*Triphane*) MONO. $a : b : c = 1.124 : 1 : 0.636$ $\beta = 69° 40'$ $LiAlSi_2O_6$

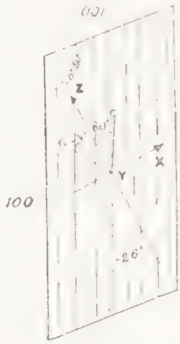

FIG. 114.—Optic orientation of spodumenite.

COMP.—Many analyses of spodumenite show surplus Al_2O_3 (and usually also SiO_2); this is, perhaps, in crystal solution. The amount of surplus Al_2O_3 attains 15 per cent according to recent analyses of samples from Madagascar.[43] Doelter [44] considers this to be due to alteration or imperfect analyses (incomplete recovery of Li_2O).

PHYS. CHAR.—Crystals prismatic, often flattened parallel to 100 and vertically striated. Twinning on 100. Distinct 110 cleavages at 87°, parting on 010; rarely on 100. H. = 6–7. G. = 3.1–3.2. F. = 3.5 (1380° C.), after turning white, swelling and giving a bright red flame color. Insoluble in acids.

OPT. PROP.—The optic plane is parallel to 010; the positive acute bisectrix Z makes an angle with c of 23° to 27° in the obtuse angle β.

	San Diego [45] (Kunzite)	N. Carolina [46] (Hiddenite)	Brazil [47]	Finland [48]	Madagascar [43] (Hiddenite)	Madagascar [43] (Kunzite)
$LiAlSi_2O_6\%$ =	89.2	87.4	83.6	77.4	40.8	46.6
(+) 2V =	....	....	54°–60°	67° 40′	55° 57′	68° 54′
N_g =	1.679	1.677 Na	1.676 Li	......	1.6815	1.6758
N_m =	....	1.669	1.666	1.6748	1.6712	1.6653
N_p =	1.652	1.651	1.660	......	1.6682	1.6603
$N_g - N_p$ =	0.027	0.026	0.016	......	0.0133	0.0155
$Z \wedge c$ =	[illegible] 24′		[illegible]	25° 45′	[illegible]	[illegible]

Color white, yellowish, greenish, emerald green (*hiddenite*), lilac (*kunzite*). Usually colorless in thin section and colorless to weakly pleochroic in thick plates, but deeply colored varieties are pleochroic in thin section as follows:

	Kunzite	Hiddenite
X =	amethystine purple	green
Y =	pink or amethystine	greenish
Z =	colorless	colorless

[43] Duparc, Wunder and Sabot: *Mem. Soc. Phys. Nat. Hist. Genève*, XXXVI, 3, 1910, p. 401.

[44] C. Doelter: *Hdb. Mineralchemie*, II, 2, 1917, p. 198.

[45] W. T. Schaller: *Univ. Cal. Dept. Geol. Bull.* III, 1903, p. 265.

[46] A. Des Cloizeaux: *Am. Jour. Sci.*, CXXXII, 1886, p. 204.

[47] A. Lacroix: *Minéraux des Roches*, 1888, p. 266. Analysis by F. Pisani: *Compt. Rend.*, CLXXXIV, 1877, p. 1509.

[48] E. Mäkinen: *Bull. Com. Geol. Finlande*, No. 35, 1915.

The pleochroic formula of hiddenite is obtained by assuming that it has the same absorption formula as kunzite, namely, X > Y > Z.

ALTER.—Spodumenite may alter to a fibrous mass of eucryptite and albite.

OCCUR.—Chiefly in pegmatite; also in gneiss. Rare.

DIAG.—Differs from other monoclinic pyroxenes, except clinoenstatite, in the extinction angle and differs from clinoenstatite in the position of the optic plane; also characterized by mode of occurrence and presence of much lithium.

Pyroxmangite[49] $\{(Fe,Mn)SiO_3\}$ is triclinic with perfect 110 and distinct $1\bar{1}0$ cleavages and 010 parting. The prismatic cleavage angle is 88° 10′ and the angles from 010 to the prism faces are 42° 56′ and 45° 14′. H. = 5.5–6. G. = 3.80. F. = 3. Insoluble in acids. The optic plane is (nearly) normal to 010 and, in a plane parallel to *c* and normal to 010, the extinction angle ($Z' \wedge c$) is about 45°. (+) $2V = 30°$, $N_m = 1.755 \pm$, $N_g - N_p = 0.01 \pm$. Color brown to yellowish. Alters to a black oxide of manganese and iron. Very rare.

Sobralite[50] $\{CaMgFe_2Mn_4(SiO_3)_8?\}$ is triclinic with perfect 110 and distinct $1\bar{1}0$ cleavages and a poorer cleavage parallel to *c* (and *a*?). G. = 3.50. The optic plane is nearly normal to a prism face ($1\bar{1}0$?) in which the extinction angle ($Z' \wedge c$) is large (40°±). $Z \wedge c = 46°$ (nearly in the plane of *a* and *c*); $Y \wedge c = 57°$; $X \wedge c = 63°$. (+) $2V = 41°$, $\rho < v$ distinct. N_m = about 1.74, $N_g - N_p = 0.0204$, $N_m - N_p = 0.0025$. Color brownish to lilac; colorless in section. Found in veins at Tunaberg, Sweden.

RHODONITE TRIC. $a : b : c = 1.073 : 1 : 0.721$ $CaMn_5(SiO_3)_6$?

$$\alpha = 103° \ 18' \quad \beta = 108° \ 44' \quad \gamma = 81° \ 39'$$

COMP.—Usually considered $MnSiO_3$, but the natural mineral *always* contains considerable Ca and pure artificial $MnSiO_3$ is positive[51] while natural (zinc-free) rhodonite is negative.

PHYS. CHAR.—Crystals often rough 001 tablets with perfect 110 and $1\bar{1}0$ and good 001 cleavages. H. = 5.5–6.5. G. = 3.4–3.68. F. = about 1200° C. Slightly attacked by acids.

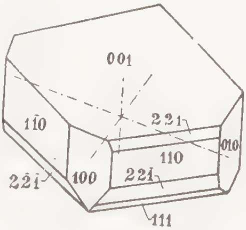

FIG. 115.—A crystal habit of rhodonite.

OPT. PROP.—The optic plane (in rhodonite from Pajsberg with about 77. $MnSiO_3$, 17. $CaSiO_3$ and 6. $FeSiO_3$) makes angles of 63° with $1\bar{1}0$ and 38.5° with 001; X is normal to a plane making angles of 51° 40′ with 001 and 51° 47′ with $1\bar{1}0$; Z is normal to a plane making angles of 80° 55′ with 001 and 50° 7′ with $1\bar{1}0$; the extinction on 100 is inclined 32° 26′ and 44° 16′ to the edges 110 and 001 respectively; the extinction on 010 is at 10° 48′ and 97° 56′ to 100 and 001 respectively; the extinction on 001 is at 54° 27′ and 39° 37′ to 110 and $1\bar{1}0$

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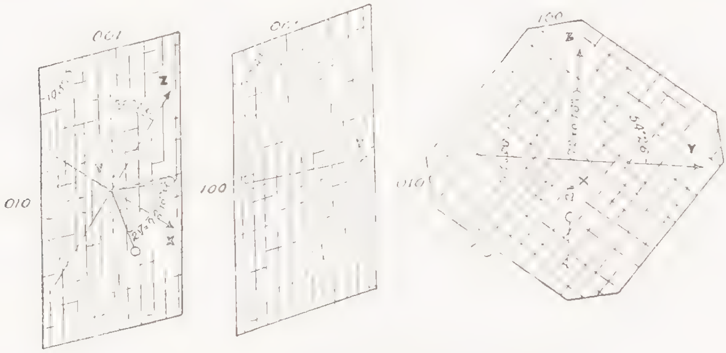
[49] W. E. Ford and W. M. Bradley: *Am. Jour. Sci.*, CLXXXVI, 1913, p. 169.

[50] J. Palmgren: *Bull. Geol. Inst. Univ. Upsala*, XIV, 1917, p. 109; also J. M. Sobral: *Bull. Geol. Inst. Univ. Upsala*, XVIII, 1922, p. 47.

[51] S. Kallenberg: *Cent. Min.*, 1914, p. 388. For a more complete discussion of the composition see A. N. Winchell: *Am. Mineral.*, XII, 1927, p. 10.

respectively. (−) 2V = 76°, $\rho < v$ weak, with marked crossed dispersion. $N_g = 1.730$[52]–1.744,[53] $N_m = 1.726$–1.740. $N_p = 1.721$–1.733, $N_g - N_p = 0.009$–0.011.



Figs. 116–118.—Optic orientation of rhodonite.

Color reddish, brown, pink, yellowish or gray; brown to black by alteration. Colorless in thin section, but in thick plates, X = clear reddish yellow, Y = pinkish red, Z = pale reddish yellow, though the chief axes of absorption and pleochroism coincide only roughly with X, Y and Z.

Alter.—Rhodonite changes to pyrolusite by weathering, or to rhodochrosite and then pyrolusite. Many names have been proposed for partly altered rhodonite, including *marceline*, *dyssnite* and *stratopeite* produced by oxidation, *hydrorhodonite* and *klipsteinite* produced by hydration, and *allagite* and *photicite* produced by carbonation.

Occur.—In ore deposits of manganese, iron, copper, etc., usually closely associated with rhodochrosite.

Diag.—Rhodonite differs from the ordinary monoclinic pyroxenes in having inclined extinction in all sections of the vertical zone; it has weaker birefringence than any other pyroxene except enstatite and clinoenstatite; it is rich in manganese.

Fowlerite[54] $\{Ca(Mn,Fe,Zn)_5(SiO_3)_6?\}$ is a zinkiferous variety of rhodonite or an independent species. It is triclinic with perfect 110, 1̄10 and 001 cleavages and lamellar 001 twinning. The prismatic cleavage angle is 87° 20′ and the angle 001 110 is 67° 3′. H. = 6. G. = 3.67. A section parallel to 110 shows two cleavages at 68° with extinction at 22° to 001. (+) 2V = moderate to large, $\rho < v$ distinct, $N_g = 1.709$–1.737, $N_m = 1.692$–1.730, $N_p = 1.687$–1.726, $N_g - N_p = 0.022$–0.011. Color pink to brownish. Found at Franklin, N. J., etc.

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[52] J. Jakob: *Schweiz. Min. Pet. Mit.*, III, 1925, p. 236.

[53] E. S. Larsen: *U. S. Geol. Surv. Bull.* 679, 1921, p. 126.

[54] E. S. Larsen and E. V. Shannon: Am. Mineral, VII, 1922, pp. 95 and 149.

Bustamite[55] ($CaMnSi_2O_6$?) is triclinic with very perfect 010, less perfect 110 and $1\bar{1}0$ and poor 100 cleavages. The cleavage angle 010 : 100 is 94° 33′, and 010 to $1\bar{1}0$ is 44° 58′. Related in angles to wollastonite, though that is monoclinic. Partly decomposed by acids. Optic plane and X nearly normal to 010 in which $Z' \wedge c = 36°$. (−) $2V = 44°$, $\rho < v$ weak with strong crossed dispersion. $N_g = 1.676$, $N_m = 1.674$, $N_p = 1.662$, $N_g - N_p = 0.014$. Color pink, fading in the light. Found at Franklin, N. J.

BABINGTONITE TRICLINIC $Ca(Fe,Mn)Si_2O_6$ with Fe_2O_3 and SiO_2

$a : b : c = 1.069 : 1 : 0.631$[56] $\alpha = 104° 21'$ $\beta = 108° 31'$ $\gamma = 83° 34'$

COMP.—The components of babingtonite are not certainly known; it may be a variety of bustamite rich in $FeSiO_3$, and containing Fe_2O_3 and SiO_2 in crystal solution.

PHYS. CHAR.—Crystals small short prisms with 001, etc. Perfect $1\bar{1}0$ and good 110 cleavages. H. = 5.5–6. G. = 3.36. F. = 3, to black magnetic globule. Insoluble in acids.

OPT. PROP.—The optic plane is nearly parallel with 110, and normal to $1\bar{1}0$; extinction at 44° on 100 and at 31° on 010 measured to c. Extinction at about 40° to c on 110. Marked dispersion. (+) $2V = 60°–65°$, $\rho > v$ strong. $N_g = 1.746$, $N_m = 1.726$, $N_p = 1.713$, $N_g - N_p = 0.033$.

Color greenish to brownish black in mass; in section X = dark emerald to bluish green, Y = pale violet brown or claret, Z = dark to pale brown or grass green.

OCCUR.—In cavities in granite, syenite, gneiss, etc., often associated with epidote and garnet. Also in Bessemer slags.

DIAG.—Differs from other pyroxenes by triclinic character, marked dispersion and strong pleochroism.

WOLLASTONITE MONO. $a : b : c = 1.052 : 1 : 0.969$ $\beta = 84° 35'$ (CaSiO

COMP.—Wollastonite can take into crystal solution[57] up to 3 per cent SiO_2, 17 per cent $CaMgSi_2O_6$ (diopside), 65 per cent $Ca_2MgSi_2O_7$ (akermanite) or 45 per cent $Ca_3Si_2O_7$. Pseudowollastonite can take in crystal solution up to 2 per cent SiO_2, 16 per cent $CaMgSi_2O_6$, 25 per cent $Ca_2MgSi_2O_7$, 20 per cent $Ca_3Si_2O_7$ or 100 per cent $SrSiO_3$. The solubility of other metasilicates has not been determined.

PHYS. CHAR.—Crystals commonly 100 or 001 tablets with perfect 100, and good 001 cleavages; imperfect $\bar{1}01$ and $\bar{1}02$ cleavage or parting. Twinning on 100. H. = 4.5–5. G. = 2.915. F. = 1540° C., after inversion at 1200° C. Decomposed by HCl.

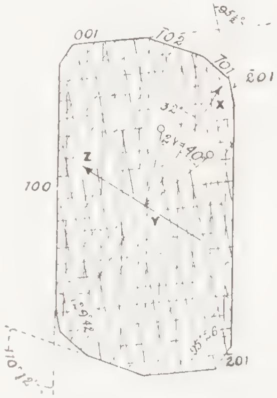

FIG. 119.—Optic orientation of wollastonite.

OPT. PROP.—The plane of the optic axes is parallel to 010 and normal[58] to the elongation, which is commonly parallel to b. The negative acute bisectrix X makes an angle of 32° with c in the acute angle β. Optic angle moderate with $\rho > v$ weak, and distinct inclined dispersion.

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[55] E. S. Larsen and E. V. Shannon: *Am. Mineral.*, VII, 1922, p. 95.

[56] M. Watanabé uses a different orientation (*Am. Jour. Sci.*, CCIV, 1922, p. 159) with 001 as the perfect cleavage and 100 as the other cleavage. He gives: $N_g = 1.740$, $N_m = 1.725$, $N_p = 1.715$, $N_g - N_p = 0.025$. Extinction on his 001 is at about − 5° to a.

[57] Ferguson and Merwin: *Am. J. Sc.*, CXCVIII, 1919, p. 165.

[58] The writer finds elongation of positive sign in all sections of wollastonite from Bingham, Utah, which is perhaps due to elongation parallel to $\bar{1}02$.

	Artificial [59]	Calif. [60]	Hungary	Finland	Idaho [61]
$(-)\ 2V =$	39°	35°	40°±	.....	Large
$N_g =$	1.631	1.631	1.635 Na	1.634	
$N_m =$	1.629	1.629	1.633	1.632	1.620
$N_p =$	1.616	1.614	1.621	1.619	
$N_g - N_p =$	0.015	0.017	0.014	0.015	

Color white or gray; rarely yellowish; colorless in thin section.

INVER.—A reversible inversion occurs at 1200° C. to *pseudowollastonite,* which is pseudohexagonal and probably monoclinic. It occurs in equant grains with basal cleavage and H. = 5; G. = 2.905; $(+)\ 2E = 0°$ to $8°$; $N_g = 1.651$, $N_m = 1.611$, $N_p = 1.610$, $N_g - N_p = 0.041$. May show lamellar twinning on the base with $X \wedge a = 2°$. Colorless. Found only in slags.

ALTER.—Changes easily to calcite.

OCCUR.—Especially in contacts of igneous intrusions and limestone, often associated with diopside, garnet, epidote and calcite.

DIAG.—Differs from pectolite and tremolite by the variable sign of elongation and the weaker birefringence; from zoisite and colorless epidote by lower refringence and smaller optic angle.

ALAMOSITE MONO. $a : b : c = 1.375 : 1 : 0.924$ $\beta = 84°\ 10'$ $PbSiO_3$

PHYS. CHAR.—Crystals fibrous parallel to *b* with perfect 010 cleavage. H. = 4.5. G. = 6.49. F. = 3. Soluble in HNO_3 yielding silica jelly.

OPT. PROP.—The optic plane is 010, and extinction is parallel to fibers, but the relation to 001 is not known. Optic sign negative.[62] $(-)\ 2V = 65°$ Na, $\rho < v$ strong, with weak inclined dispersion. $N_g = 1.968$, $N_m = 1.961$, $N_p = 1.947$, $N_g - N_p = 0.023$ (meas). Colorless or white; adamantine luster.

OCCUR.—With quartz, cerussite, wulfenite, etc., in lead deposits. Very rare.

Merwinite [63] $\{Ca_3Mg(SiO_4)_2\}$ is monoclinic with perfect 010 cleavage. H. = 6. G. = 3.15. Fusible. Gelatinizes with acid. Multiple twinning common with *c* as twinning axis and 110 as composition face, the twins forming an angle of 43°; also twinning on 100. Optic plane normal to 010; $X \wedge c = 36°$. $(+)\ 2V = 67°$, $\rho > v$ weak. $N_g = 1.718$, $N_m = 1.711$, $N_p = 1.708$, $N_g - N_p = 0.010$. Colorless. Found in contact zones in California. Rare.

AMPHIBOLE GROUP

The minerals of the amphibole group are orthorhombic and monoclinic metasilicates of magnesium, iron and calcium, commonly with double silicates of sodium and ferric iron or aluminum, and with alumina or ferric iron oxide (or both) in some cases.

PHYS. CHAR.—The crystals usually show decided vertical elongation and may be finely fibrous. They have well developed prismatic cleavages at an angle of about 124°. Twinning on 100 is common and may be multiple. The specific gravity ranges from 2.9 to 3.55 and the hardness from 4 to 6.5. The minerals are fusible at 4 to 6, and insoluble, except slowly in HF.

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[59] F. E. Wright: *Am. J. Sc.*, CLXXXIX, 1915, p. 6.

[60] A. S. Eakle: *Bull. Dept. Geol. U. Calif.*, X, 1917, p. 327.

[61] E. V. Shannon: *U. S. Nat. Mus. Bull.* 131, 1926, p. 283.

[62] Given as positive by Kraus, Cooper and Klein: *Cent. Mineral.*, 1912, p. 289.

[63] E. S. Larsen and W. F. Foshag: *Am. Mineral.*, VI, 1921, p. 143.

Opt. Prop.—The plane of the optic axes is parallel to 010 (except in certain alkaline types), and in monoclinic amphiboles the axis Z makes an angle with the vertical axis c of 0° to 25° in the obtuse angle β, with similar exceptions. These angles are shown in Fig. 120.

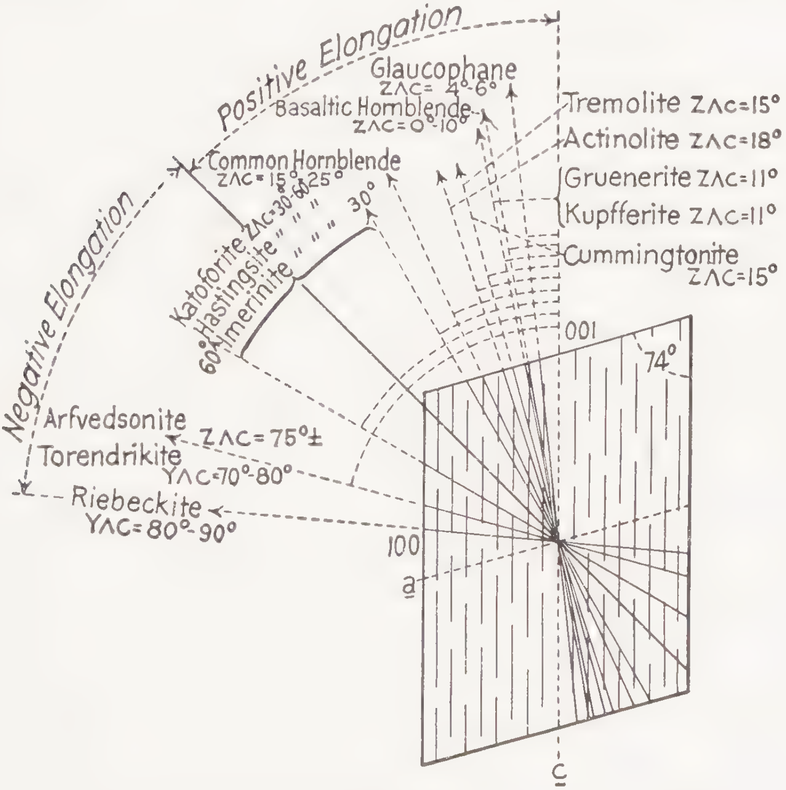

Fig. 120.—Diagram of extinction angles ($Z \wedge c$) in monoclinic amphiboles.

The average refringence is less than that of the pyroxenes; it increases with the tenor of iron. The birefringence of common types is about 0.020 to 0.025, but in gruenerite and "basaltic" hornblende it is much more. Amphiboles in thin section are green, brown, yellow, blue or colorless; pleochroism is usually distinct and it is intense in the highly ferriferous types. In the common varieties absorption is greatest parallel to Z and least parallel to X.

Alter.—Amphiboles alter readily to chlorite, biotite, antigorite, epidote, calcite, talc, etc. The alteration to chlorite, biotite, antigorite or talc is a gradual process, usually beginning along the edges and cleavages of the amphibole, and sometimes continuing until no trace of the original mineral, except perhaps its form, is to be found. Under the action of intense heat, as, for instance, when fragments of amphibole crystals are caught in volcanic rocks, the mineral is often rounded, corroded and more or less fused. Upon cooling the amphibole does not recrystallize; in its place appear grains of magnetite, microlites of pyroxene, or an aggregate of these two minerals. Similarly, when amphiboles are artificially fused and allowed to cool the crystallized product is not amphibole, but a pyroxene, commonly with magnetite.

Occur.—Amphiboles are found in nearly all classes of igneous, and in many metamorphic, rocks. In some cases they are sufficiently abundant to constitute rocks, with other minerals so subordinate in amount as to be merely accessory. Amphiboles are often formed by the alteration of pyroxenes.

Diag.—Amphiboles may be distinguished from pyroxenes thus:

Amphiboles	Pyroxenes
Cleavage angle about 124°.	Cleavage angle about 93°.
Crystals usually long prismatic.	Crystals usually short prismatic.
Color and pleochroism usually marked.	Color and pleochroism usually weak.
Maximum extinction angle in vertical zone 0°-25° (except certain alkaline types with unusual colors).	Maximum extinction angle in vertical zone 30°-54° (except certain alkaline types with unusual colors).
Most species negative.	Most species positive.
Alter to chlorite, etc. (change to pyroxene only through fusion).	Alter to amphibole, etc.

Class.—The amphiboles are orthorhombic or monoclinic[64] in symmetry. The orthorhombic amphiboles belong to a single continuous isomorphous series from $MgSiO_3$ to $FeSiO_3$ in which limited amounts of $AlAlO_3$, $CaSiO_3$, $MnSiO_3$, $NaAlSi_2O_6$ and apparently H_2SiO_3 are soluble in the crystal state. The whole series is known as anthophyllite, the pure $MgSiO_3$ being called magnesioanthophyllite (or maganthophyllite), the pure $FeSiO_3$ ferroanthophyllite (or feranthophyllite), and the type with notable alumina and negative sign gedrite.

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[64] Enigmatite and rhoenite are usually considered to be triclinic amphiboles, but they differ from amphiboles in composition and properties, and are here considered by themselves.

The monoclinic amphiboles are more complex; crystals corresponding to any simple formula or to indefinite mixtures of any two (or even three) component molecules are not common; most of the analyzed crystals are found to contain from four to ten or more molecules. However, by disregarding the less important molecules these minerals may be assigned to the following types and systems:

Kupfferite—$MgSiO_3$—(purity found only in artificial crystals).

Gruenerite—$FeSiO_3$—(natural crystals about 80 per cent pure).

These two form a series, probably continuous, known as:

Cummingtonite—$(Mg,Fe)SiO_3$.

$NaFeSi_2O_6$ does not occur alone as an amphibole, but forms mix-crystals (or double salts) with $FeSiO_3$ and with $MgSiO_3$, known as

Riebeckite—$NaFeSi_2O_6 \cdot FeSiO_3$ and

Torendrikite—$NaFeSi_2O_6 \cdot MgSiO_3$ (very rare).

$NaAlSi_2O_6$ does not occur alone as an amphibole, but is known in three- and four-component mix-crystals called

Glaucophane—$NaAlSi_2O_6 \cdot mFeSiO_3 \cdot nMgSiO_3$ and

Crossite—$NaAlSi_2O_6 \cdot mNaFeSi_2O_6 \cdot nFeSiO_3 \cdot pMgSiO_3$ (rare).

$CaSiO_3$ does not form an amphibole by itself, but probably forms double salts with $MgSiO_3$ and $FeSiO_3$, thus:

——— —$CaMgSi_2O_6$ (unknown in nature; probably formed [65] artificially).

——— —$CaFeSi_2O_6$ (hypothetical).

Natural mixtures of $MgSiO_3$ and $CaMgSi_2O_6$, when crystallized without sesquioxides occur about in the ratio 2 : 1 in

Tremolite—$CaMgSi_2O_6 \cdot 2(\pm)MgSiO_3$.

Similarly, natural mixtures of $FeSiO_3$ and $CaFeSi_2O_6$, when crystallized without sesquioxides, are found about in the ratio 2 : 1, but are unknown alone and are most important in crystal solution in tremolite, in the type known as

Actinolite—$Ca(Mg,Fe)Si_2O_6 \cdot 2(\pm)(Mg,Fe)SiO_3$.

Both these mix-crystals containing calcium, when crystallized with important amounts of sesquioxides, are found in variable ratios averaging about 1 : 1; sesquioxides may occur in small amount in nearly any kind of amphibole, but reach 10–25 per cent in the following types:

Gastaldite—$NaAlSi_2O_6 \cdot m(Fe,Mg)SiO_3 \cdot nAl_2O_3$.

Pargasite—$Ca(Mg,Fe)Si_2O_6 \cdot (Mg,Fe)SiO_3 \cdot mNaAlOF_2 \cdot nAl_2O_3$.

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[65] A. N. Winchell: *Am. Jour. Sci.*, CCVII, 1924, p. 287.

Hornblende—$Ca(Mg,Fe)Si_2O_6 \cdot (Mg,Fe)SiO_3 \cdot mNaAlOF_2 \cdot nNaSiO_2OH \cdot p(Al,Fe)_2O_3$.

Pargasite is characterized by the presence of 5–20 per cent of the peculiar molecule, $NaAlO(F,OH)_2$. In hornblende this molecule is usually less abundant and poorer in fluorine. A molecule, $NaSiO_2(F,OH)$, containing fluorine or hydroxyl in a similar way, is found in hornblende and is important in:

Arfvedsonite $FeSiO_3 \cdot mNaSiO_2(F,OH)$

and there is apparently a complete series of gradations from hornblende to arfvedsonite.

In tabular form the amphiboles may be arranged as follows:

Species	Subspecies	Composition	Axial Ratio	β
		ORTHORHOMBIC		
			c	
	Maganthophyllite	$MgSiO_3$	0.51 : 1 : 0.2+	90°
Anthophyllite	Feranthophyllite	$FeSiO_3$		
	Gedrite	$(Mg,Fe)SiO_3 \cdot mAl_2O_3$	0.523 : 1 : 0.217	90°
		MONOCLINIC		
	Kupfferite	$MgSiO_3$		
	Cummingtonite	$(Mg,Fe)SiO_3$		
	Gruenerite	$FeSiO_3$		
	Riebeckite	$NaFeSi_2O_6 \cdot FeSiO_3$	0.5475 : 1 : 0.2295	76° 10′
	Torendrikite	$NaFeSi_2O_6 \cdot MgSiO_3$		
	Glaucophane	$NaAlSi_2O_6 \cdot (Mg,Fe)SiO_3$	0.53 : 1 : 0.29	75° ±
	Tremolite	$CaMgSi_2O_6 \cdot 2(\pm)MgSiO_3$	0.5415 : 1 : 0.2886	74° 48′
Amphibole...	Actinolite	$Ca(Mg,Fe)Si_2O_6 \cdot 2(\pm)(Mg,Fe)SiO_3$	0.54 : 1 : 0.29	75° ±
	Pargasite	$Ca(Mg,Fe)Si_2O_6 \cdot (Mg,Fe)SiO_3 \cdot mNaAlOF_2 \cdot nAl_2O_3$	0.551 : 1 : 0.294	73° 58′
	Hornblende	$Ca(Mg,Fe)Si_2O_6 \cdot (Mg,Fe)SiO_3 \cdot mNaAlOF_2 \cdot nNaSiO_2OH \cdot p(Al,Fe)_2O_3$	0.551 : 1 : 0 294	73° 58′
	Arfvedsonite	$FeSiO_3 \cdot mNaSiO_2(F,OH)$	0.55 : 1 : 0.29	75° 44′

ANTHOPHYLLITE ORTH. $a : b : c = 0.51 : 1 : 0.2+$ $(Mg,Fe)SiO_3$

COMP.—Common anthophyllite is dominantly magnesian, but types are found varying from pure magnesium to pure iron metasilicate, and any of these may contain up to about 20 per cent Al_2O_3; finally, appreciable amounts of other metasilicates are not uncommon (especially in types with iron) including $CaSiO_3$, H_2SiO_3, $MnSiO_3$, etc. The pure magnesium type has been called *magnesioanthophyllite* by Shannon,[66] and the pure iron type *ferroanthophyllite*; these names are so long that the shorter forms *maganthophyllite* and *feranthophyllite* are suggested. Aluminous anthophyllite has long been called *gedrite*.

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[66] E. V. Shannon: *Proc. U. S. Nat. Mus.*, LIX, 1921, p. 397.

PHYS. CHAR.—Crystals rare, usually fibrous, sometimes like asbestus. Perfect 110 cleavages at 125° 37′. G. = 2.857 (pure $MgSiO_3$) to 3.2 (with much Fe). H. = 5.5–6. F. = 4–6. Insoluble in acids.

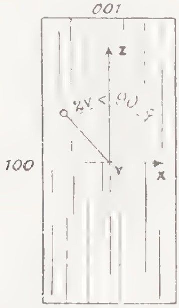

FIG. 121.—Optic orientation of anthophyllite.

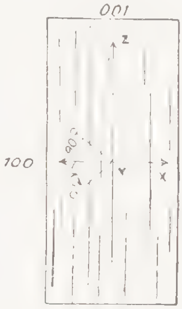

FIG. 122.—Optic orientation of gedrite.

OPT. PROP. The optic plane is parallel to 010; Z is parallel to *c*, and the elongation is positive; anthophyllite is usually positive, but gedrite is negative and feranthophyllite is perhaps negative. The optic angle is always large with $\rho > v$ about Z. The variations in physical characters with variations in tenor of $FeSiO_3$ are shown in Fig. 123, and in the following illustrations:

	Artificial[67]	Idaho[68]	Franklin, N. C.[67]	Kongsberg[69]	Orijarvi[70]	Idaho[68]	Mesabi[71]	Fiskernäs[72]
$\%FeSiO_3=$	0.0	10.5	19.5	27.6	48.2	60.	69.4	2.8
$2V=$	......	(+) Large	(−)88° 46′ Na	(+)84°	70°–80°	....	....	(−)78° 33′
$N_g=$	1.597	1.625	1.6404	1.657	1.676	1.685	1.698	1.6439
$N_m=$	......	....	1.6301	1.642	1.662	....	....	1.6358
$N_p=$	1.584	1.605	1.6105	1.633		1.668		1.623
$N_g-N_p=$	0.013	0.020	0.0299	0.024		0.017		0.0209

[67] N. L. Bowen: *Jour. Wash. Acad. Sci.*, X, 1920, p. 411. A sample from Edwards, N. Y., with 2.77 MnO and only .06 FeO has N_g = 1.62 (*Am. J. Sc.*, CLXXVI, 1908, p. 111).

[68] E. V. Shannon: *U. S. Nat. Mus. Bull.* 131, 1926, pp. 286 and 288.

[69] A. Lacroix: *Minéral. France*, I, 1895, p. 636.

[70] P. Eskola: *Bull. Com. Géol. Finlande*, XL, 1915, p. 176, and errata.

[71] Unpublished.

[72] N. V. Ussing: *Zeit. Kryst.*, XV, p. 609. Gedrite with 21.8 Al_2O_3.

As the alumina increases the optic angle about Z increases, changing sign when it passes through 90°; at the same time the refringence increases slightly.

Color brown to green; colorless in thin section, but in thick sections, X = brownish, Y = brownish, Z = yellow or pale green.

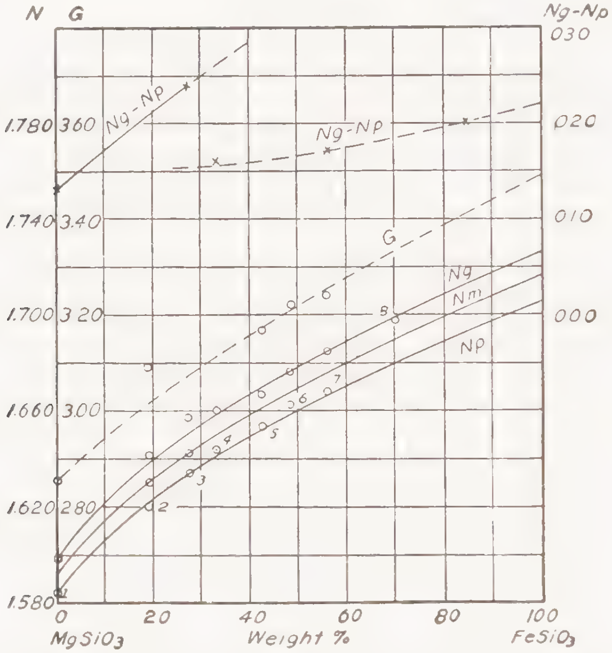

FIG. 123.—Variations of composition and optic properties in the anthophyllite series.

INVER.—Maganthophyllite is the least stable form of $MgSiO_3$,[73] which inverts irreversibly at 400° C. and above to the monoclinic form, kupfferite, which inverts at about 1150° C. to enstatite, which is less stable than clinoenstatite. The formation of maganthophyllite seems to depend upon pressure, or excess silica, or both.

INCL.—Gedrite often contains inclusions of biotite, spinel, zircon, etc.; it may contain inclusions like those giving name to bronzite.

ALTER.—Changes rather easily to talc, bastite, etc.

OCCUR.—In various schists and contact rocks, and also, as a secondary product, in igneous rocks.

DIAG.—Easily distinguished from monoclinic amphiboles by parallel extinction in vertical sections and lack of color.

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[73] *Amer. Jour. Sci.*, CLXXII, 1906, p. 385.

KUPFFERITE[74] MONOCLINIC $MgSiO_3$

COMP.—Natural kupfferite commonly contains some $FeSiO_3$, $CaSiO_3$, etc. Pure artificial crystals are finely fibrous.

PHYS. CHAR.—Crystals prismatic with good 110 cleavages at 55° 30′. G = 3.08 (natural crystal). F. = 5–6. Insoluble in acids.

OPT. PROP.—The optic plane is parallel to 010; the extinction angle ($Z \wedge c$) in the vertical zone attains about 11° in the pure artificial substance, and is decidedly oblique in the natural crystals. On artificial crystals Wright[75] found the indices to be very nearly the same as (or slightly higher than) for the orthorhombic form on which Bowen[67] determined: $N_g = 1.597$, $N_m = ?$, $N_p = 1.584$, $N_g - N_p = 0.013$. Such crystals are positive[76] with a large optic angle. The artificial mineral is colorless, but the natural product is usually emerald green, probably on account of the presence of some Cr_2O_3.

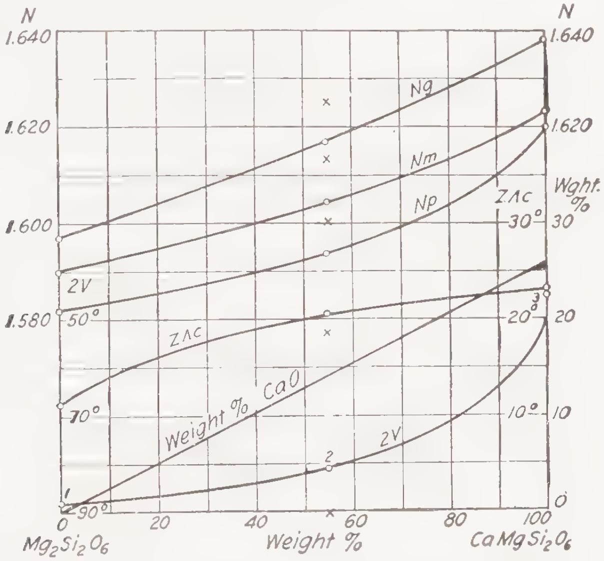

FIG. 124.—Variations in composition and optic properties in the $Mg_2Si_2O_6 - CaMgSi_2O_6$ series of monoclinic amphiboles (including kupfferite and tremolite).

INVER.—Kupfferite may be formed by inversion of maganthophyllite in the presence of water at about 400° C., and inverts to pyroxene at 1150° C. or lower. These inversions are monotropic.

OCCUR.—Kupfferite is found in calcite in Siberia and the Urals, and in aggregates in granite in the Ilmen Mountains. Rare.

DIAG.—Distinguished by the lowest refringence found among the monoclinic amphiboles.

Richterite $\{(Mg,Mn,Ca)SiO_3\}$ is a variety of kupfferite containing Mn, Ca, Fe, Na, K, H. The extinction angle ($Z \wedge c$) is 15° to 20°; the optic angle is large and dispersion weak, $\rho < v$. (−) 2V = 68°±, $N_g = 1.636$, $N_m = 1.629$, $N_p = 1.615$, $N_g - N_p = .021$. Color brown to yellow; rarely rose-red, blue or violet. Pleochroism weak with X = pale yellowish, Y = colorless, Z = yellowish brown. Found in rare alkaline rocks in Sweden.

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[74] This name was originally given by Kokscharow to a monoclinic amphibole, largely $MgSiO_3$. Dana and others have applied the name to orthorhombic amphibole. It is here used in the original sense.

[75] *Am. Jour. Sci.*, CLXXII, 1906, pp. 403, 431.

[76] *Am. Jour. Sci.*, CCVII, 1924, p. 296.

CUMMINGTONITE MONOCLINIC $(Mg,Fe)SiO_3$

PHYS. CHAR.—Crystals fibrous or lamellar with good 110 cleavages at 54° 48′. G. = 3.1–3.3. F. = 5–6. Insoluble in acids.

OPT. PROP.—The plane of the optic axes is parallel to 010; the extinction angle ($Z \wedge c$) in the vertical zone reaches 14° to 20°. The optic angle is large with $\rho < v$.

(+) 2V = 78°±, $N_g = 1.667 \pm$, $N_m = 1.650 \pm$, $N_p = 1.639 \pm$, $N_g - N_p = 0.028 \pm$.

The variations in optical properties with changes in composition are shown graphically in Fig. 126.

Color brown; only slightly colored in section with X = Y = very pale yellowish, Z = clear brownish yellow.

OCCUR. — In contact and ore deposits. Rare.

DIAG. — Differs from anthophyllite in its inclined extinction and from actinolite in its optic sign, slightly higher density and refringence and low tenor of calcium.

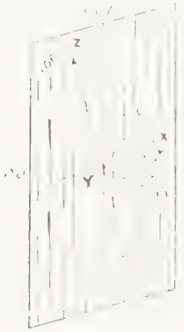


FIG. 125.—Optic orientation of cummingtonite.

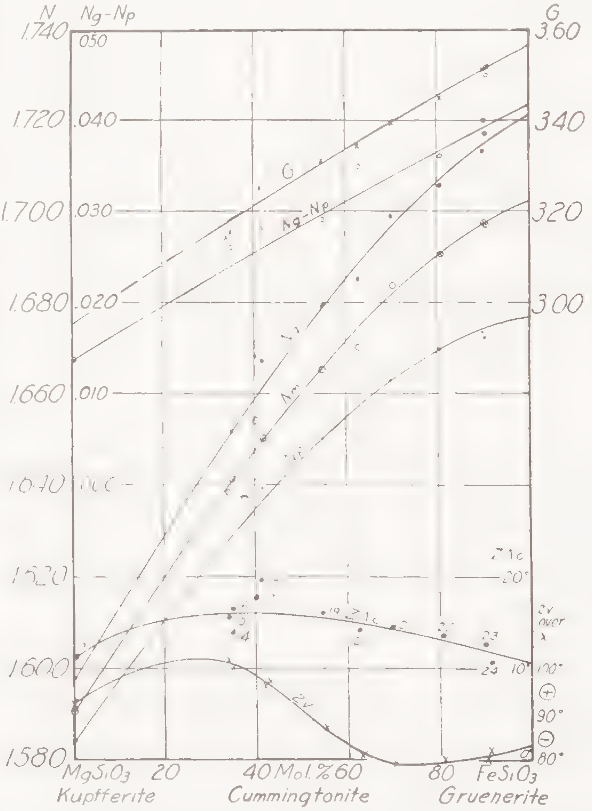


FIG. 126.—Variations in composition and optic properties in the kupfferite-cummingtonite-gruenerite series.

Dannemorite $(Mg,Mn,Fe)SiO_3$ is a variety containing manganese. Crystals are lamellar or acicular. H. = 5.5. G. = 3.4–3.5. F. = 5 to dark slag. Insoluble in acids. Optic plane is 010 and $Z \wedge c$ = about 14°. Optic angle about X is large. Colorless or gray to yellow and pleochroic. Found in iron deposits, etc., in Sweden. Rare.

GRUENERITE Monoclinic $FeSiO_3$

Phys. Char.—Usually in fibrous or lamellar masses with perfect 110 cleavages at 124°. Multiple twinning on 100 very common. G. = 3.7 ±. Fusible to a black magnetic glass.

Opt. Prop.—The optic plane is parallel to 010; the extinction angle ($Z \wedge c$) attains 10° to 15° in the vertical zone. Birefringence strong. Optic angle large with $\rho > v$, and weak inclined dispersion. On a mineral with 2.61 MgO and 1.90 CaO:

(−) 2V = 82°±. $N_g = 1.717$ Na, $N_m = 1.697$, $N_p = 1.672$, $N_g - N_p = 0.045$.

Fig. 127.—Optic orientation of gruenerite.

Color brown; luster silky. Weakly pleochroic in section with X = Y = colorless, Z = pale yellow to brownish or greenish; in thicker sections X = colorless, Y = pale brownish, Z = greenish.

Occur.—In mica schists in Europe and in highly altered rocks of the Lake Superior iron region.

Diag.—Characterized by multiple twinning, high index and strong birefringence; brown "basaltic" hornblende is the only amphibole with greater birefringence.

Hastingsite ($FeSiO_3 \cdot nNaFeSi_2O_6$) is intermediate between gruenerite and riebeckite in composition and optical properties as shown in the diagram (Fig. 128). H. = 6.

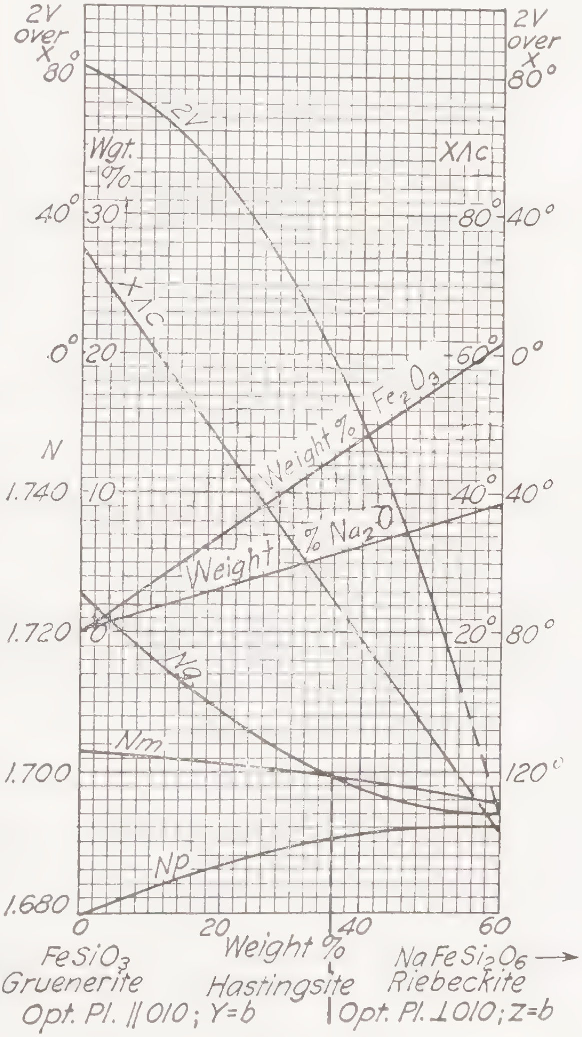


Fig. 128.—Variations in composition and optic properties in the gruenerite-riebeckite series.

G. = 3.2. The optic angle is very small, passing through zero with small changes of composition, the optic plane changing at the same time from 010 to normal thereto. The extinction angle ($Z \wedge c$) varies from 25° to 30°. (−) $2V = 0°–12°\pm$, $N_m = 1.69$, $N_g - N_p$ = weak. Color blue-green with X = yellow-green, Y = Z = deep blue-green. Found in alkaline igneous rocks in Canada. Rare.

RIEBECKITE Mono. $a : b : c = 0.547 : 1 : 0.229$ $\beta = 76° 10'$ $NaFeSi_2O_6 \cdot FeSiO$

Phys. Char.—Crystals prismatic, vertically striated, with perfect 110 cleavages at 124°. Fibrous varieties are called *crocidolite* or blue asbestus. H. = 4. G. = 3.443 F. = 3(?). Insoluble in acids.

Opt. Prop.—The optic plane and Z are normal to 010; the acute bisectrix X makes an angle of 0° to 5° with c in the acute angle β. The optic angle is very large, the dispersion is very strong, and the birefringence very weak; these characters with the intense color make precise measures very difficult. Negative; also reported as positive.

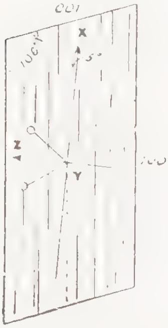


Fig. 129.—Optic orientation of riebeckite.

(−) 2V = large, $N_g = 1.697$, $N_m = 1.695$, $N_p = 1.693$, $N_g - N_p = 0.004 \pm$. $X \wedge c = 0°$ (red) to 5° (blue).

Color dark blue to black; strongly pleochroic with X > Y > Z and X = dark indigo blue, steel blue, green blue or smoky green, Y = blue or greenish or brownish yellow, Z = yellowish green or dark grayish green to black.

Occur.—Riebeckite is found in sodic igneous rocks and in some metamorphic rocks.

Diag.—Characterized by intense color and pleochroism, strong dispersion and negative elongation; much like glaucophane, but differs in sign of elongation.

Crossite $\{NaFeSi_2O_6 \cdot mNaAlSi_2O_6 \cdot n(Fe,Mg)SiO_3\}$ is intermediate between riebeckite and glaucophane in composition, but more like the former in optic properties. G. = 3.16. Optic plane and Z are normal to 010, and $X \wedge c = 60°–80°$. Optic angle about X variable to zero, with very strong dispersion; as the optic angle passes through zero the optic plane changes from 010 to normal thereto and the dispersion changes from $\rho < v$ to $\rho > v$, both very strong. Also strong dispersion of bisectrices, preventing extinction in white light in sections normal to Z. (−) 2V = 0° to moderate, $N_g = 1.663$, $N_m = 1.659$ (to $1.670 \pm$), $N_p = 1.657$, $N_g - N_p = 0.006$ (or more). Color bluish black and strongly pleochroic with X = colorless to bright yellow, Y = sky to dark blue, Z = deep violet. Found in schists and contact rocks in Calfornia and Colorado. Rare.

TORENDRIKITE Monoclinic $NaFeSi_2O_6 \cdot MgSiO_3$

Phys. Char.—Crystals prismatic with perfect 110 cleavages at 124°. H. = 5. G. = 3.21.

Opt. Prop.—The optic plane is reported to be parallel to 010 by Lacroix,[77] but the relations of the mineral to the $MgSiO_3–FeSiO_3–NaFeSi_2O_6$ system as shown in Fig. 130 suggest that the optic plane is normal to 010, and this has been confirmed by the writer on a sample kindly supplied by Professor Lacroix. The extinction angle ($X \wedge c$) is about 50°. The optic angle is so large that the sign is undetermined. The dispersion is very strong. $N_m = 1.665 \pm 5$, $N_g - N_p = 0.02$ about.

[77] *Comp. Rend.*, CLXXI, 1920, p. 594.

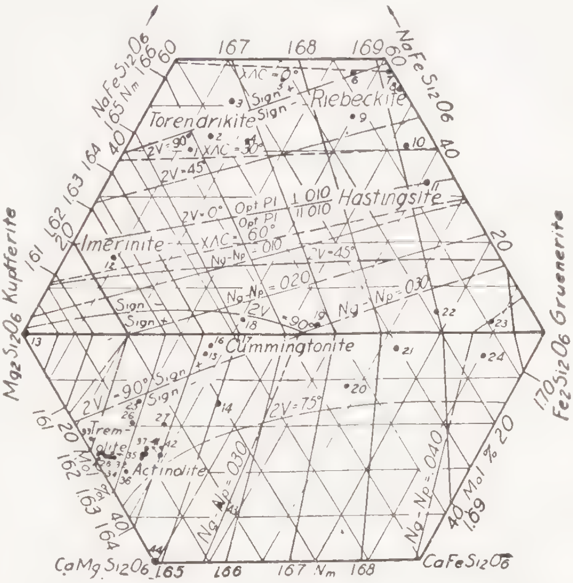


FIG. 130.—Variations in composition and optic properties in the torendrikite-kupfferite-tremolite-gruenerite-riebeckite system.

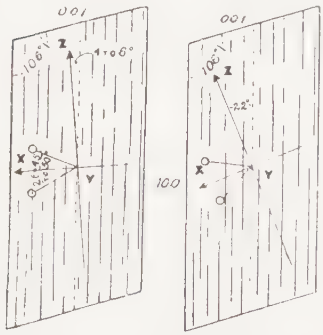
Color dark blue; strongly pleochroic with the pleochroic axes not coincident [78] with X, Y and Z, but nearly parallel with *a*, *b*, and *c*; and *a* = clear greenish yellow, *b* = violet gray, and *c* = sea green; the absorption is: $a < c < b$.

OCCUR. — In contact zones in Madagascar. Very rare.

DIAG.—The optic orientation and pleochroism are distinctive.

Imerinite [79] ($MgSiO_3 \cdot mNaFeSi_2O_6$) is intermediate between kupfferite and torendrikite in composition and characters. Perfect 110 cleavages at 124° 42′. H. = 5.5. G. = 3.0. Optic plane parallel to 010, but the optic angle is very small; the extinction angle ($Z \wedge c$) attains 45°, both are variable. The optic sign is negative. Very strong dispersion of optic axes and bisectrices. $N_g = 1.653$, $N_p = 1.638$, $N_g - N_p = 0.015$. Color blue with X = pale yellowish green, Y = violet blue, Z = pale bluish green and Y > X = Z. Found in limestones modified by intrusive granites in Madagascar. Very rare.

GLAUCOPHANE MONO. $a : b : c = 0.53 : 1 : 0.29$ $NaAlSi_2O_6 \cdot m(Fe,Mg)SiO_3$
$\beta = 75° \pm$



FIGS. 131, 132.—Optic orientation of glaucophane and abnormal glaucophane.

PHYS. CHAR.—Crystals prismatic with perfect 110 cleavages at 124°. H. = 6–6.5. G. = 3–3.15. F. = 3–3.5. Insoluble in acids.

OPT. PROP.—The optic plane is parallel to 010; the extinction angle ($Z \wedge c$) reaches $+ 4°$ to $+ 6°$ in the vertical zone. Optic angle moderate about X with $\rho > v$, strong. (−) $2V = 45° \pm \rho > v$, $N_g = 1.639$, $N_m = 1.638$, $N_p = 1.621$, $N_g - N_p = 0.018$ to 0.022. Color lavender blue to bluish black with distinct and characteristic pleochroism, varying in intensity, as follows: X = colorless, yellowish, or greenish yellow, Y = violet blue, Z = lavendar to dark Prussian blue.

ALTER.—Glaucophane may be the product of alteration of pyroxene and it may alter to a green sodic hornblende; if the transformation is incomplete the mineral may be called an abnormal glaucophane; it then has a maximum extinction angle ($Z \wedge c$) in the vertical zone of 16°, or even 20° or 22°; at the same time the color parallel to Z becomes a pale greenish blue.

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[78] *Bull. Soc. Fr. Min.*, XLVII, 1924, p. 32. [79] *Minéral. France*, IV, 1910, p. 787.

OCCUR.—Only in schists or similar metamorphic rocks.

DIAG.—Easily distinguished by its blue color, marked pleochroism, and positive elongation.

Gastaldite $\{NaAlSi_2O_6 \cdot m(Fe,Mg)SiO_3 \cdot nAl_2O_3\}$ is an aluminous glaucophane. H. = 6. G. = 3–3.1. Optic plane is 010; $Z \wedge c = 4°–8°$. $(-)\ 2V = 42°–44°$, $\rho > v$, weak. $N_g = 1.649$, $N_m = 1.646$ (to 1.656), $N_p = 1.630$ (to 1.640), $N_g - N_p = 0.019$. Has slightly higher refringence and much weaker dispersion than glaucophane.

TREMOLITE MONOCLINIC $CaMgSi_2O_6 \cdot 2(\pm)MgSiO_3$
↕ $a : b : c = 0.5415 : 1 : 0.2886$ ↕
ACTINOLITE $\beta = 74° 48'$ $\left\{ Ca(Mg,Fe)Si_2O_6 \cdot 2(\pm)(Mg,Fe)SiO_3 \right.$

COMP.—Natural tremolite consists chiefly of $CaMgSi_2O_6$ and $MgMgSi_2O_6$ in nearly equal parts, and actinolite consists of the same molecules with a little $CaFeSi_2O_6$—in very rare cases reaching about 50 per cent. Both commonly contain, also, small amounts of alkalies and water, perhaps as $NaFeSi_2O_6$ and H_2SiO_3. $CaMgSi_2O_6$ is unknown in nature as an amphibole, but a melt of this composition (plus 15 per cent SiO_2) produced crystals[80] with cleavages like amphiboles and having $(+)\ 2V = 45°\pm$, $N_g = 1.638$, $N_p = 1.620$, $N_g - N_p = 0.018$; colorless.

PHYS. CHAR.—Crystals long bladed to acicular and fibrous; rarely short prismatic. Perfect 110 cleavages at 124° 11′. Distinct 100 or 010 parting in some crystals. H. = 5–6. G. = 2.9–3.2, increasing with iron. F. = 4. Insoluble in acids.

OPT. PROP.—The plane of the optic axes is parallel to 010 and the extinction angle ($Z \wedge c$) in the vertical zone varies from 15° to 18°; the optical angle is large about X with $\rho < v$, weak. The relations between composition and optical characters are shown in Fig. 134.

	Gouverneur, N. Y.	Pierrepont	Zillerthal
$\%CaFeSi_2O_6 =$	1.0	7.9	18.9
$(-)\ 2V =$	81° 33′	84° 5′	79° 49′
$N_g =$	1.6244	1.6319	1.6410
$N_m =$	1.6131	1.6210	1.6297
$N_p =$	1.5996	1.6065	1.6139
$N_g - N_p =$	0.0248	0.0244	0.0271
$Z \wedge c =$	16° 39′	16° 54′	16° 31′

Tremolite is colorless, gray or yellow; colorless in section. Actinolite is pale to dark green, darker with increase of iron. In section X = very pale yellow, Y = greenish yellow, Z = pale to dark green.

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[80] N. L. Bowen: *Am. Jour. Sci.*, CLXXXVIII, 1914, p. 209.

INVER.—Change to pyroxene (probably pigeonite) at high temperatures.

INCL.—Inclusions of carbonaceous matter or biotite are not rare.

ALTER.—Alteration to talc usually begins along cleavage planes; other alteration products include chlorite, epidote, calcite, etc.

OCCUR.—Found in schists and contact rocks; also in veins, and in igneous rocks as an alteration product.

VARIETIES.—*Asbestus* of commerce is a fibrous mineral which may be a variety of tremolite, actinolite, riebeckite, anthophyllite, or chrysotilite; the best asbestus is the last type. *Jade* is a tough, compactly interlaced fibrous mineral, white to dark green in color, used by early man for ornaments. It is commonly tremolite or actinolite; sometimes it is a variety of jadeite, one of the pyroxenes. *Uralite* is a name given to amphibole which is produced by the alteration of pyroxene. It is usually actinolite, but may be tremolite or hornblende.

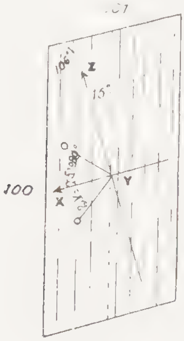


FIG. 133.—Optic orientation of actinolite.

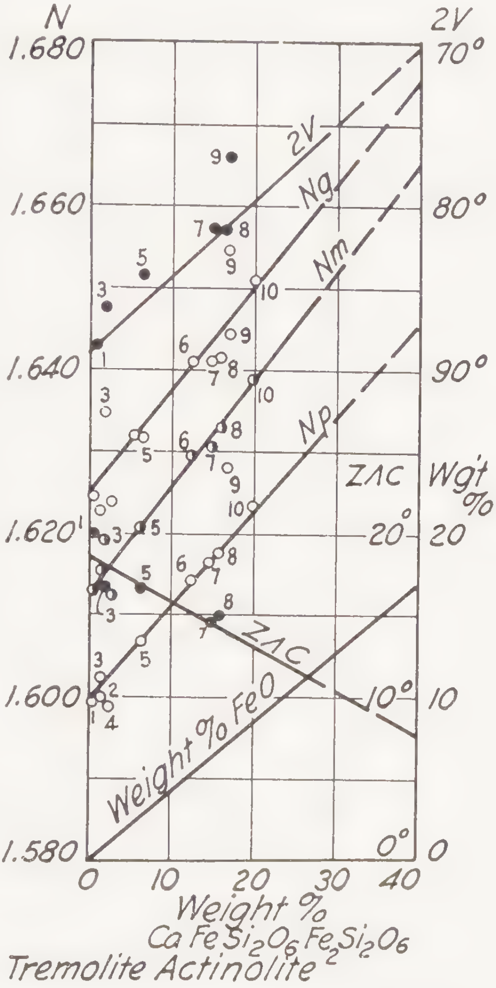


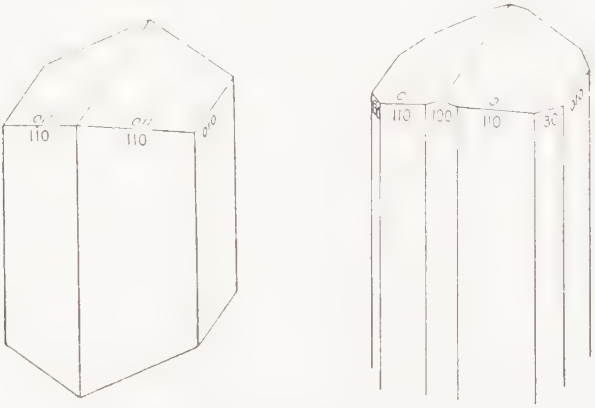
FIG. 134.—Variations in composition and optic properties in the tremolite-actinolite series.

DIAG.—Tremolite differs from hornblende and actinolite in the absence of color; except for the very rare kupfferite, tremolite has the lowest indices of refraction found in the monoclinic amphiboles. Wollastonite and pyroxenes differ in their cleavages. Actinolite is distinguished from hornblende by absence of alumina, different etching figures on the cleavage faces and different usual mode of occurrence. Epidote has its optic plane normal to the cleavage.

PARGASITE MONOCLINIC $Ca(Mg,Fe)Si_2O_6\cdot(Mg,Fe)SiO_3$
↕ $a : b : c = 0.551 : 1 : 0.294$ $\cdot mNaAlOF_2\cdot nAl_2O_3$
HORNBLENDE $\beta = 73° 58'$ $Ca(Mg,Fe)Si_2O_6\cdot(Mg,Fe)SiO_3$
$\cdot mNaAlOF_2\cdot nNaSiO_2OH$
$\cdot p(Al,Fe)_2O_3$

COMP.—The formulas are only approximations; the actual composition is very complex and variable. *Basaltic hornblende* is characterized by abundant titanium (Ti_2O_3?) (and, or) Fe_2O_3 and alkalies. Titaniferous hornblende is also known as *kaersutite*.

PHYS. CHAR.—Crystals usually elongated prisms; also fibrous; rarely short prismatic. Perfect 110 cleavages at 124° 11′; also distinct 010 cleavage. Parting on 100 or 001 accompanied by lamellar twinning. G. = 3–3.47, increasing with iron content. H. = 5.5. F. = 3–4. Insoluble in acid.



FIGS. 135, 136.—Crystal habits of hornblende.

OPT. PROP. The plane of the optic axes is parallel with 010; the elongation parallel to the cleavages and the vertical axis is positive, and the extinction angle ($Z \wedge c$) in 010 in the obtuse angle β varies from about 15° to 25° with variations in composition. The relief is moderate and the birefringence is not very strong. The optic sign is positive in pargasite and negative in hornblende. Dispersion is $\rho < v$ in hornblende and $\rho > v$ in pargasite; inclined dispersion in both. The indices of refraction given in most textbooks for hornblende are a little too low, having been measured on pargasite and actinolite. The following data are from analyzed material.

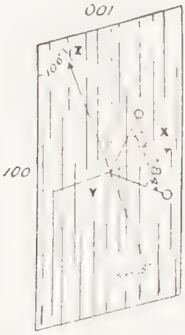


FIG. 137.—Optic orientation of common hornblende.

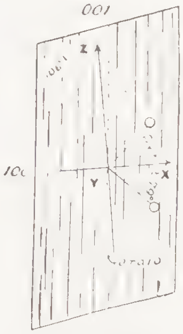


FIG. 138.—Optic orientation of basaltic hornblende.

Type	Locality	Sign	2V	N_g	N_m	N_p	$N_g - N_p$	$Z \wedge c$
Pargasite......	Grenville *	+	56° 8′	1.6328	1.6180	1.6128	0.020	29° 44′
Pargasite......	Pargas †	+	63° 1′	1.6519	1.6380	1.6329	0.019	26° 15′
Hornblende....	Edenville *	−	81° 42′	1.6789	1.6701	1.6583	0.0206	23° 48′
Hornblende....	Cerebriansky ‡	−	80° 4′	1.6843	1.6753	1.6648	0.0195	16° (average)
Hornblende....	Hungary §	−	82° 45′	1.6929	1.6825	1.6698	0.0231	9° (3.8 TiO_2)
Hornblende....	Kilimanjaro ‖	−	......	1.701	1.691	1.675	0.026	12° (4.2 TiO_2)
Basaltic hornb..	Linosa ¶	−	79° 54′	1.760	1.730	1.692	0.068	1° 24′ (8.5 TiO_2)

* W. E. Ford: *Am. Jour. Sci.*, CLXXXVII, 1914, p. 179.

† A. Laitakari: *Bull. Com. Geol. Finlande*, 54, 1920, pp. 55, 58 (Type II).

‡ L. Duparc and T. Hornung: *Arch. Sci. Nat. Phys. Genève*, XXIII, 1907, p. 3

§ M. Vendl: *Mineral. Mag.*, XX, 1924, p. 237.

‖ H. S. Washington: *Am. Mineral.*, VII, 1922, p. 121.

¶ H. S. Washington and F. E. Wright: *Am. Jour. Sci.*, CLXXVI, 1908, p. 187. $Z \wedge c$ measured on 110.

$N'_g - N'_p$ on the prismatic cleavage = 0.009–0.037.

There are so many molecules present in varying amounts in hornblende and pargasite that the relations between optical properties and composition cannot be accurately shown in any diagram, but by assuming a constant tenor of 10–15 per cent of alumina the most important remaining molecules seem to be $CaMgSiO_6 \cdot MgSiO_3$, $CaFeSi_2O_6 \cdot FeSiO_3$, $NaFeSi_2O_6$ and Fe_2O_3; by combining the last two (since their optical effects seem to be similar) the diagram given in

Fig. 139 can be constructed. It must be emphasized that this diagram is only approximate; other variable components, not shown, cause variations from the graph.

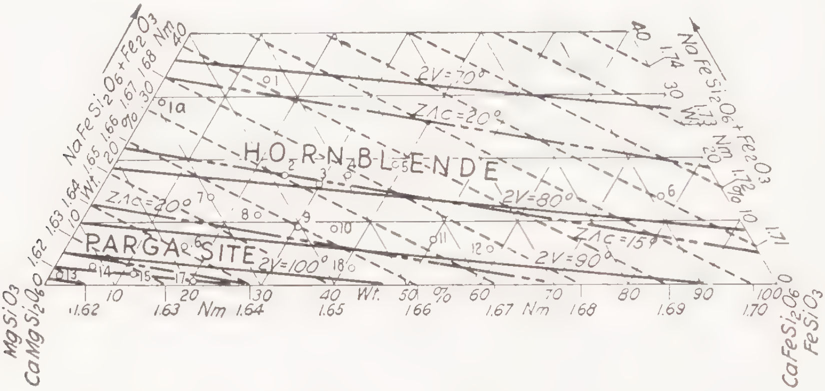


FIG. 139.—Variations in composition and optic properties in the pargasite-hornblende system.

Usually dark green or brown to black in mass or, rarely, gray or colorless (in the variety known as *edenite*). The pleochroism is generally more intense in brown than in green types. The pleochroic colors are somewhat variable, but always belong to shades or tints of green, brown or yellow. The absorption is $X < Y < Z$. Examples of the colors follow.

	X	Y	Z
Pargasite	greenish yellow	emerald green	greenish blue
Hornblende	yellow	bluish green	greenish blue
Hornblende	yellowish green	dark olive green	dark green
Hornblende	pale brownish	greenish	dark green
Hornelende	pale yellow	brownish yellow	reddish yellow
Hornblende	clear yellow	dark brown	dark brownish green
Hornblende	clear brown	pale brown	pale green
Hornblende	greenish brown	reddish brown	red brown
Basaltic hornblende	greenish yellow	brownish green	dark blue
Basaltic hornblende	pale yellow	dark brown	dark olive-green
Basaltic hornblende	pale brown or yellow	dark brown	dark brown

INVER.—Hornblende is stable (or metastable) through a considerable range of conditions, but not at high magmatic temperatures, since pyroxene (often with magnetite, and sometimes with microlitic feldspars) is produced by recrystallization after dry fusion.

INCL.—Inclusions are common, such as apatite, zircon, magnetite, etc., but none are characteristic. Vitreous inclusions occur in hornblende of some volcanic rocks; rutile is common in hornblende of metamorphic rocks.

Alter. By ordinary alteration hornblende passes into chlorite, sometimes with epidote, calcite, siderite, quartz, etc. Less commonly it alters to biotite, or to biotite and epidote. Still more rarely titanite is formed.

Occur.—The best-known occurrences of pargasite are all in contact zones. Hornblende is found in many types of igneous rocks and is especially important in diorites. It is also important in some schists and contact rocks.

Diag.—Pargasite has moderate refringence and rather strong birefringence with positive sign. Hornblende has high relief and similar birefringence with negative sign; both have perfect prismatic cleavages at an angle of 124°, and extinction angles of 15° to 25° in the vertical zone, which has positive elongation. But basaltic hornblende has still higher relief, strong to very strong birefringence, and an extinction angle near 0° (0°–15°). All have distinct green to brown color and pleochroism (except edenite and some pargasites).

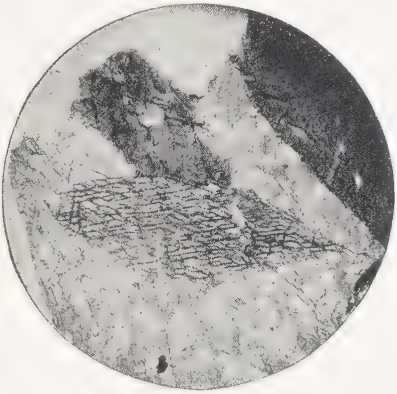


Fig. 140.—Photomicrograph of hornblende in thin section.

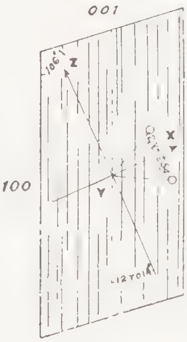


Fig. 141.—Optic orientation of barkevikite.

Barkevikite is a variety of hornblende rich in ferrous iron and alkalies, related to basaltic hornblende and kataphorite. Perfect 110 cleavages at 124° 20′. H. = 5.5. G. = 3.43. Optic plane is 010; extinction angle ($Z \wedge c$) 10°–14°. (—) $2E = 55°–95°$, $2V = 31°–52°$, $\rho > v$. $N_g = 1.701$,[81] $N_m = 1.690$, $N_p = 1.680$, $N_g - N_p = 0.021$. Color velvet black; in section strongly pleochroic with X = clear brownish to light yellow, Y = reddish brown, Z = dark brown, with $X < Y < Z$. Found in basic alkaline rocks.

[81] A. Scott: *Mineral Mag.*, XVII, 1914, p. 138.

ARFVEDSONITE MONOCLINIC $FeSiO_3 \cdot mNaSiO_2(F,OH)$

$a : b : c = 0.550 : 1 : 0.298 \quad \beta = 75° 44'$

PHYS. CHAR.—Crystals long prismatic or bladed with perfect 110 cleavages at 124° 22′. H. = 5.5. G. = 3.45. F. = 2 with intumescence to dark magnetic bead. Insoluble.

OPT. PROP.—The optic plane is parallel to 010; the vertical elongation is negative and the extinction angle ($X \wedge c$) varies from − 14° to + 20° in different cases.[82] The optic angle is very large about X. The indices have not been measured, but N_m should be about 1.69, and the birefringence is weak. Strong dispersion of the bisectrices causes incomplete extinction in white light except in section parallel to *b*.

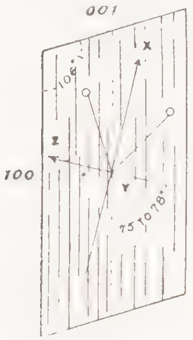


FIG. 142.—Optic orientation of arfvedsonite.

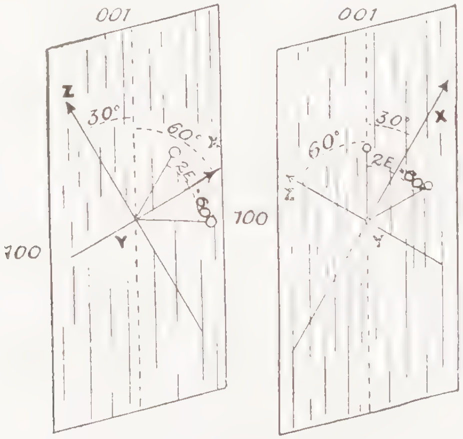
Color blue to black; pleochroism strong with X > Y > Z and X = Berlin blue to deep green, Y = violet, blue or brown, Z = greenish yellow, gray or greenish brown.

ALTER.—Arfvedsonite may be transformed (by fusion?) to acmite with lepidomelane; it alters to siderite and limonite.

OCCUR.—In sodic igneous rocks such as nephelite syenite.

DIAG.—Characterized by prismatic cleavages at 124°, negative elongation, peculiar pleochroism and absorption and an extinction angle usually larger than that of riebeckite and smaller than that of kataphorite.

Kataphorite is the name of amphibole belonging to the series between arfvedsonite and barkevikite, which is characterized by an extinction angle ($Z \wedge c$) of + 30° to + 60°, red colors, and absorption Y > Z > X. It is negative with 2E = about 60°. Pleochroism strong with X = yellowish red or reddish gray, Y = brownish red, pink, or greenish brown, Z = reddish, or greenish yellow, greenish blue or pale reddish brown. Kataphorite is often intergrown with arfvedsonite and acmite in alkaline igneous rocks. The maximum absorption parallel to Y is normal to the elongation.



FIGS. 143, 144.—Optic orientation of kataphorite.

ENIGMATITE TRICLINIC $Fe(Si,Ti)O_3 \cdot mNa(Al,Fe)Si_2O_6$

$a : b : c = 0.669 : 1 : 0.352 \quad \alpha = 90° 5' \quad \beta = 77° 30' \quad \gamma = 90° 19'$

PHYS. CHAR.—Crystals of enigmatite resemble those of amphibole, but have a prism (cleavage) angle of 114° instead of 124°. Crystals vertically elongated. Common twinning on 010, sometimes lamellar. Distinct 110 and 1$\bar{1}$0 cleavages. H. = 5.5. G. = 3.74–3.85. F. = 3. Partly decomposed by acids.

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[82] A. Johnsen: *N. Jahrb. Mineral.*, 1901, II, p. 117.

Opt. Prop.—The plane of the optic axes is nearly parallel to 010; the axis Z makes an angle of about 45° with the vertical axis c in 010 and about 4° in 100. (+) 2E = 60°±, 2V = 32°, $\rho < v$(?), $N_m = 1.80$, $N_g - N_p = 0.006$. Color black; streak reddish brown; intensely pleochroic in section with $X < Y < Z$ and X = clear reddish brown, Y = dark chestnut brown, Z = very dark brown.

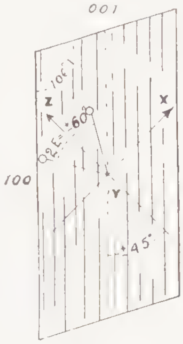

Fig. 145.—Optic orientation of enigmatite.

Occur.—In nephelite syenites, etc. Rare.

Diag.—Distinguished by intense color, pleochroism, high relief, lack of parallel extinction even in 100, and cleavage angle.

Cossyrite is similar, if not identical, but is described as monoclinic by some writers.

Rhoenite is much like enigmatite, but contains very little alkali, some $(Mg,Ca)SiO_3$ and considerable $(Al,Fe)_2O_3$. Crystal habit like hornblende; twinning on 010. G. > 3.56; about 3.58. Transparent to opaque. Streak red brown. The optic plane is inclined somewhat to 010, crossing the vertical axis from the left above to the right below. Extinction angle measured on 010 in sections normal to c is about 7°. Extinction angle ($Z' \wedge c$) in 010 is about 40° in the acute angle β. Refringence and birefringence about as in brown hornblende. Pleochroism strong with X = brown, sometimes greenish, Y = brown, Z = dark red brown to black. Found in basic igneous rocks. Rare.

TITANITE (*Sphene*) Monoclinic $CaTiSiO_5$

$$a : b : c = 0.755 : 1 : 0.854 \quad \beta = 60° 17'$$

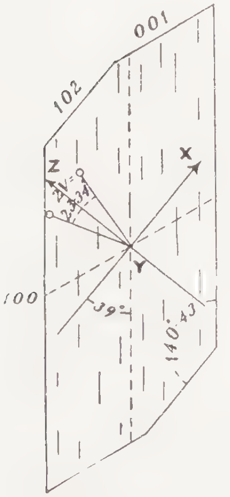

Fig. 146.—Optic orientation of titanite.

Comp.—May contain 1 to 20 per cent R_2O_3, probably as R_2SiO_5, with R = Fe, Al, Y, Ce.

Phys. Char.—Crystals often wedge-shaped with large 001 and 111 faces, but very varied; they may be elongated parallel to c or to a, or pyramidal. Twinning on 100; also lamellar on 221, due to shearing stress (may be artificially produced at 3000 atmospheres), causing parting. Distinct 110 cleavage. H. = 5–5.5. G. = 3.4–3.56. F. = 3. Soluble in H_2SO_4.

Opt. Prop.—The optic plane is parallel to 010; the positive acute bisectrix Z is nearly normal to 102, making an angle of about 51° (47°–57°) with the cleavage in the obtuse angle β. The optic angle is variable, but usually small. Weak inclined dispersion with extreme axial dispersion, $\rho > v$. Data are still insufficient to show relations between variations in composition and in optic properties, but in general increase of Fe and especially (Y,Ce) causes increase of the optic angle and indices. The following table expresses the approximate average values[83] and the known range of values.

	Average			Range
	Li	Na	Tl	Na
(+) 2V =	30°	28°	25°	23° 20′-49° 30′
N_g =	1.996	2.008	2.021	1.979 2.054
N_m =	1.895	1.905	1.917	1.894-1.935
N_p =	1.888	1.899	1.910	1.888 1.918
$N_g - N_p$ =	0.108	0.109	0.112	0.082-0.135
$Z \wedge c$		51°		47°-57°

In zonal growths the refringence and optic angle may increase from the center to the border. Color brown, yellow, gray, green, rose-red, black, often varying in a single crystal. Pleochroism usually weak in thin section, but deeply colored types show marked pleochroism especially in thick sections, as follows:

X = greenish yellow	pale brownish yellow	nearly colorless
Y = greenish pink	pale brownish yellow	greenish yellow
Z = salmon pink	pale yellow	orange brownish red

Incl.—Ripidolite lamellæ, which may be grouped at the center, form rare inclusions in titanite; albite inclusions are also known.

Alter.—Titanite may lose its color, become softer, and turn into a light yellow amorphous mass accompanied by calcite, or it may be replaced by an opaque iron oxide with more or less ilmenite, rutile, calcite, etc.

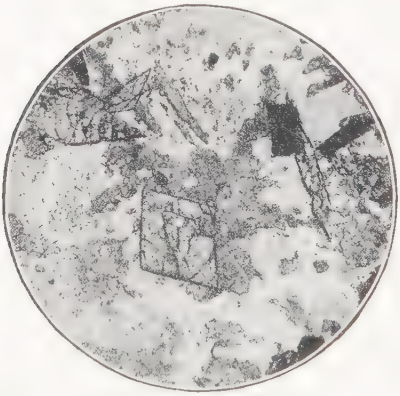

Fig. 147.—Photomicrograph of titanite in thin section.

Occur.—Titanite is very widely but sparsely distributed in rocks of all kinds. It is particularly at home in hornblende granites, syenites and diorites; the alteration product called *leucoxene*, supposed to be titanite and derived from ilmenite (or titaniferous magnetite) is common in more basic igneous rocks. Titanite is also common in schists and gneisses. It is rare in sediments.

Diag.—Titanite is characterized by its wedge-shaped forms, extreme refringence and birefringence, strong axial dispersion and positive sign.

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[83] Data for titanite from Wildkreuzjoch (K. Busz: *N. Jahrb. Min. B. B.*, V, 1887, p. 337) omitted as the birefringence is clearly in error.

Keilhauite or *yttrotitanite* is a variety of titanite containing up to about 12 per cent $(Y,Ce)_2O_3$ and about 5 per cent of Fe_2O_3 and of Al_2O_3. It is like titanite in all respects, optic data being included above. (+) 2V = 50° Na, $\rho > v$ strong, $N_g = 2.03$ Na, $N_m = 1.935$, $N_p = 1.915$, $N_g - N_p = 0.115$. $Z \wedge c = 57°$. Color brownish black, weakly pleochroic. Found in feldspathic rock in Norway. Very rare.

Trimerite $\{Be_3Mn_2Ca(SiO_4)_3\}$ is monoclinic[84] (pseudohexagonal $c = 0.942$) with $a : b : c = 0.471 : 1 : 0.577$, $\beta = 59° 51'$. Crystals thick six-sided prismatic with distinct basal cleavage. H. = 6-7. G. = 3.47. F. = 6. Soluble in HCl. Optic plane nearly normal to 100 making an angle of about 20° with 110; X nearly normal to 001. (−) 2V = 83° 29′, $N_g = 1.7253$, $N_m = 1.7202$, $N_p = 1.7148$, $N_g - N_p = 0.0105$. Color pink; colorless in section. Found in calcite in a manganese mine in Sweden. Very rare.

Guarinite or *hjortdahlite* $\{3Ca(Si,Zr)O_3 \cdot NaZrO_2F?\}$ is triclinic and pseudorhombic with $a : b : c = 0.993 : 1 : 0.370$, $\alpha = 89° 22'$, $\beta = 90° 37'$, $\gamma = 90° 6'$. Crystals 100 tablets with 110 cleavages nearly at 90°. H. = 5.5. G. = 3.27. F. = 3? Gelatinizes with HCl. Optic plane[85] nearly parallel with $\bar{1}\bar{1}1$; extinction (optic plane) on 100 is at 65° to c and on 010 it is at 75° to c; (+) 2V = near 90°, $\rho < v$, strong, $N_m = 1.695 \pm$, $N_g - N_p = 0.012$. Color yellow to brown with X = colorless to canary yellow, Y = yellowish, Z = wine to pale yellow. Found in nephelite syenite. Very rare. Differs from woehlerite and laavenite in having only moderate birefringence.

Hainite is closely related to guarinite, but probably contains Ce. Crystals prismatic with distinct 010 cleavage and twinning on 100. H. = 5. G. = 3.18. F. = 4 ±. Decomposed by HCl. Optic plane and Z nearly normal to 010; extinction on 100 nearly parallel to c, on 010 at about 4° to c, and in a section normal to c at about 16.5° to b. Extinction imperfect on account of strong dispersion of bisectrices. (+) 2V = large, $\rho > v$, $N_m = 1.7 \pm$, $N_g - N_p = 0.012$. Color and pleochroism as in guarinite. Found in phonolite. Very rare. Differs from guarinite in having positive elongation.

Margarosanite[86] $(CaPbSi_3O_9)$ is triclinic with $a : b : c = 0.750 : 1 : 1.285$, $\alpha = 74° 37'$, $\beta = 50° 28'$, $\gamma = 78° 53'$; crystals lamellar to acicular with perfect 010 cleavage; two other cleavages nearly normal to 010 make angles of 78° and 102°. H. = 2.5-3. G. = 3.99. F. = 2 in R. F.; about 6 in O. F. In 010 tablets $X' \wedge$ cleavages = 44° and 34°; in these tablets $N'_g = 1.795$, $N'_p = 1.73$. (−) 2V = 83°, $\rho < v$. $N_g = 1.807$, $N_m = 1.773$, $N_p = 1.729$, $N_g - N_p = 0.078$. Colorless to white. A very similar mineral from Sweden[87] has three cleavages, one 010 perfect, and one (001) good. G. = 4.39 and $Z \wedge c = 8° 40'$ in acute angle β. Margarosanite is found at Franklin, N. J., with almandite, willemite, etc.

4. SILICATES OF DIVALENT BASES WITH HYDROGEN, FLUORINE, CHLORINE, OR SULPHUR

Helvite $\{MnS \cdot 3Be(Mn,Fe)SiO_4\}$ is isometric; crystals tetrahedral with poor 111 cleavage. H. = 6. G. = 3.2. F. = 3. Gelatinizes with HCl with evolution of H_2S. Isotropic with N = 1.739. Color yellow, brown, green; in thin section yellowish. Found in gneiss, pegmatite and syenite. Rare. Characterized by high relief, isotropic character and common triangular sections.

[84] G. Aminoff: *Geol. För. Förh.*, XLVIII, 1926, p. 19.

[85] See also E. S. Larsen: *U. S. Geol. Surv. Bull.* 619, 1921, p. 82.

[86] W. E. Ford and W. M. Bradley: *Am. J. Sci.*, CXCII, 1916, p. 159.

[87] G. Flink · *Geol. För. Förh. Stockholm*, 1917, p. 426.

Danalite $\{RS \cdot 3Be(Fe,Zn,Mn)SiO_4\}$ is similar with H. = 6. G. = 3.43. F. = 3. Isotropic with N = 1.737. Color red to gray; paler in section. Found in granite. Rare.

GANOMALITE	HEXAGONAL[1]	$Ca_4Pb_4(PbOH)_2(Si_2O_7)_3$
NASONITE	$c = 1.3167$	$Ca_4Pb_4(PbCl)_2(Si_2O_7)_3$

COMP.—Crystallographically it is probable that Cl and OH replace O; if so, the formula may perhaps be written $Ca_4Pb_6Si_6O_{21}(Cl,OH)_3$ and the minerals may then be considered as derived from Si_6O_{24}, or the orthosilicate radical.

PHYS. CHAR.—Crystals hexagonal prisms with basal and hexagonal prismatic cleavages. H. = 3. G. = 5.57–5.7 (ganomalite), 5.43 (nasonite). F. = easy. Gelatinizes with HCl.

OPT. PROP.—Uniaxial positive; also ganomalite weakly biaxial. Colorless to gray.

	Ganomalite		Nasonite	
	Larsen	Zenzén	Larsen	Aminoff
$N_o =$	1.910	....	1.917	1.9453 Na
$N_e =$	1.945	....	1.927	1.9716
$N_e - N_o =$	0.035	.009–.050	0.010	0.0263

The data strongly suggest that there is a complete series from ganomalite to nasonite and that the birefringence decreases from .050 to .009 as OH is replaced by Cl.

OCCUR.—In calcite veins at Franklin, N. J., and Langban, Sweden. Very rare.

Molybdophyllite $\{Pb(OH)_2 \cdot MgSiO_3\}$ is trigonal with $c = 0.549$; the formula may also be written: $MgPbSiO_4 \cdot H_2O$; correct formula unknown. Crystals foliated with perfect 001 cleavage. H. = 3–4. G. = 4.72. F. = diff. Uniaxial negative with $N_o = 1.815$, $N_e = 1.761$, $N_o - N_e = 0.054$. Pale green in mass; colorless in section. Found with hausmannite in granular carbonate rock.

FRIEDELITE	TRIGONAL	$c = 0.562$	$H_2SiO_3 \cdot mMn(Cl,OH)_2 \cdot nMnSiO_3$
PYROSMALITE	TRIGONAL	$c = 0.530$	$H_2SiO_3 \cdot m(Fe,Mn)(Cl,OH)_2 \cdot n(Fe,Mn)SiO_3$

COMP.—The formula is often written as an orthosilicate, $H_7(MnCl)Mn_4Si_4O_{16}$; the correct formula is unknown, but probably similar to that of molybdophyllite since the X-ray patterns are much alike.[2]

PHYS. CHAR.—Crystals hexagonal plates with perfect 0001 cleavage. H. = 4–5. G. = 3.06–3.19. F. = 3–4 to black glass. Gelatinizes with HCl.

OPT. PROP.—Uniaxial negative with strong birefringence. Also biaxial with 2V = small.

Friedelite . .	$N_o = 1.65$	$N_e = ?$	$N_o - N_e = 0.03$	
	$N_o = 1.664$	$N_e = 1.629$	$N_o - N_e = 0.035$	
Pyrosmalite	$N_o = 1.675$	$N_e = 1.636$	$N_o - N_e = 0.039$	Larsen
	$N_o = 1.682$	$N_e = 1.647$	$N_o - N_e = 0.035$	Flink[3]

Friedelite is slightly biaxial with $11\bar{2}0$ as optic plane in some cases. Color of friedelite rose-red to colorless; in sections 0.5 mm. thick, pleochroic with X = very pale yellow, Z = dark reddish brown. Color of pyrosmalite dark green to pale brown; also gray to pale green, brown apparently due to surface oxidation; thick plates pleochroic with O > E. Both are (nearly) colorless in thin section.

OCCUR.—In manganese and iron mines. Very rare.

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[1] N. Zenzén: *Geol. För Förh. Stockholm*, XXXVII, 1915, p. 294; XXXVIII, 1916, p. 477 and G. Aminoff: *op. cit.*, p. 473.

[2] G. Aminoff: *Geol. För. Förh. Stockholm*, XL, 1918, p. 923; XLI, 1919, p. 213.

[3] G. Flink: *Ark. Kemi. Min. Geol.*, VI, 1917, No. 21.

Parsettensite [4] ($3MnO \cdot 4SiO_2 \cdot 4H_2O$?) is hexagonal (?) with platy basal cleavage. F. = easy. Decomposed by HCl. Uniaxial negative with $N_o = 1.576$, $N_e = 1.546$, $N_o - N_e = 0.030$. Color copper red, with X = greenish yellow, Z = pale yellow to colorless. Found in ore deposits. Very rare.

Errite is considered a variety of parsettensite with an extra $Mn(OH)_2$ group and a browner color. It is uniaxial negative with $N_o = 1.575$, $N_e = 1.547$, $N_o - N_e = 0.028$. G. = 2.68.

DIOPTASITE (*Dioptase*) TRIGONAL $c = 0.534$ H_2CuSiO_4

COMP.—Formula also written $(CuOH)HSiO_3$; also $CuSiO_3 \cdot H_2O$.

PHYS. CHAR.—Crystals prismatic with perfect $10\bar{1}1$ cleavage. H. = 5. G. = 3.05–3.35. F. = 7, but decrepitates and gives green flame color. Gelatinizes with HCl.

OPT. PROP.—Uniaxial positive; also biaxial with six or three sectors in basal sections; in such crystals the optic plane is parallel to 010 and 2V may attain 43°.

	Lacroix, 1893	Ites, 1903	Quercigh,[5] 1914
$N_o =$	1.644 Na	1.6580 Na	1.6573–1.6584 D
$N_e =$	1.697	1.7097	1.7085–1.7094
$N_e - N_o =$	0.053	0.0517	0.0510–0.0513

$N'_e - N_o$ on the cleavage [6] = 0.014.

Color emerald green; weakly pleochroic in thick sections with X > Z.

OCCUR.—In copper deposits. Rare.

Hilledrandite $\{(CaOH)_2SiO_3\}$ is orthorhombic; crystals fibrous with prismatic cleavages. H. = 5.5. G. = 2.69. F. = diff. to white glass. Soluble in HCl. The optic plane is (apparently) 010; Z = c. (−) 2E = 70°±, $\rho < v$ strong. $N_g = 1.612$, $N_m = 1.61 \pm$, $N_p = 1.605$, $N_g - N_p = 0.007$. Color porcelain white or greenish; colorless in section. Found with carbonate, yellow garnet and wollastonite in a contact zone in Mexico. Very rare. Moderate relief and optic angle, weak birefringence, and strong dispersion, producing abnormal interference colors, are distinctive.

HEMIMORPHITE (*Calamine*) ORTHORHOMBIC $(ZnOH)_2SiO_3$

$a : b : c = 0.784 : 1 : 0.478$

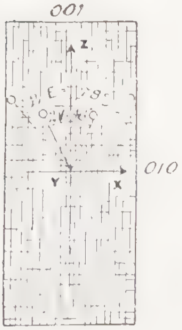

FIG. 148.—Optic orientation of hemimorphite.

COMP.—Formula also written $ZnSiO_4 \cdot H_2O$.

PHYS. CHAR.—Crystals distinctly hemimorphic when doubly terminated. Often in sheaf-like aggregates. Perfect 110 and imperfect 101 cleavages. Rare twinning on 001. H. = 5. G. = 3.45. F. = 6 with bright light. Gelatinizes with HCl.

OPT. PROP.—The optic plane is 100; the positive acute bisectrix Z is normal to 001. (+) 2V = 46°, $\rho > v$ distinct. $N_g = 1.636$, $N_m = 1.617$, $N_p = 1.614$, $N_g - N_p = 0.022$.

Colorless, white, pale bluish or greenish, gray, brown.

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[4] J. Jakob: *Schweiz. Min. Pet. Mit.*, III, 1923, p. 227.

[5] E. Quercigh: *Rend. R. Accad. Sc. Fis. Mat. Napoli*, 1914. From *N. Jahrb. Min.*, 1916, I, p. 159.

[6] H. Buttgenbach: *Minéraux et Roches*, 1916, p. 508.

Incl.—Greenockite (CdS) has been found in fine particles along surfaces of growth of hemimorphite.

Occur.—In veins with sphalerite and smithsonite; also disseminated in limestone with sulphides.

Diag.—Strong dispersion, mode of occurrence and crystal forms are distinctive.

Stokesite ($H_4CaSnSi_3O_{11}$) is orthorhombic with $a : b : c = 0.346 : 1 : 0.804$. Crystals pyramidal with 010 large. Perfect 110 and imperfect 010 cleavages. H. = 6. G. = 3.19. The optic plane is 010; $X = a$. (+) $2V = 69.5°$ Na, $\rho < v$. $N_g = 1.619$, $N_m = 1.6125$, $N_p = 1.609$, $N_g - N_p = 0.010$. Colorless. Found with axinite in Cornwall. Very rare.

HUMITE FAMILY

The humite family consists of four chief minerals which are orthosilicates of magnesium with the radical Mg(F,OH). From the symmetry of the optic properties three of the family are monoclinic and one (humite) is orthorhombic, but the variation of the angle β in all is so slight it has not been measured, and Mallard considers humite also monoclinic with apparent orthorhombic symmetry due to submicroscopic twinning. The family is closely related to the olivine group.

In physical characters the minerals of the family are very similar. The monoclinic members show multiple twinning on 001 which is supposed to exist as submicroscopic twinning in the orthorhombic member, humite. They all have distinct 001 cleavage, which is not well marked in thin section. H. = 6-6.5. G. = 3.1–3.2. Color yellow to reddish brown in mass; colorless to bright yellow in section.

The length of the vertical axis varies with the number of atoms of magnesium, as shown in the following table, in which the relation to forsterite of the olivine group is also shown.

		$\frac{1}{2}b : a : c$	β
Forsterite	Mg_2SiO_4	$1.072 : 1 : 2 \times 0.6288$	90°
		$a : b : c$	
Norbergite	$Mg[Mg(F,OH)]_2SiO_4$	$1.0803 : 1 : 3 \times 0.6287$	90° 0′
Chondrodite	$Mg_3[Mg(F,OH)]_2(SiO_4)_2$	$1.0863 : 1 : 5 \times 0.6289$	90° 0′
Humite	$Mg_5[Mg(F,OH)]_2(SiO_4)_3$	$1.0802 : 1 : 7 \times 0.6329$	90°
Clinohumite	$Mg_7[Mg(F,OH)]_2(SiO_4)_4$	$1.0803 : 1 : 9 \times 0.6288$	90° 0′
Titanclinohumite[7]	$Mg_7(MgOH)_2[(Si,Ti)O_4]_4$	$1.0735 : 1 : 9 \times 0.6297$	89° 59′ 34″

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[7] F. Zambonini (*Bull. Soc. Fr. Min.*, XLII, 1919, p. 250) has shown that so-called titanolivine belongs here, and contains hydroxyl as given above.

Norbergite[8] $[Mg\{Mg(F,OH)\}_2SiO_4]$ is massive with H. = 6.5, G. = 3.14. Gelatinizes with HCl. Biaxial positive with $2V = 49\frac{1}{2}°$, $N_g = 1.590$, $N_m = 1.567$, $N_p = 1.563$, $N_g - N_p = 0.027$. Found in iron ore in Sweden; very rare.

CHONDRODITE MONOCLINIC $Mg_3Mg(F.OH)_2(SiO_4)_2$

$a : b : c = 1.0803 : 1 : 3.1445 \quad \beta = 90$

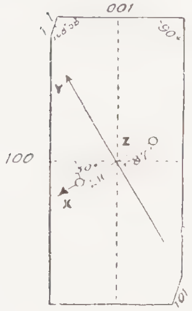


FIG. 149.—Optic orientation of chondrodite.

PHYS. CHAR.—Crystals often 010 tablets, varied in habit, with 001 cleavage not distinct in section. Multiple twinning on 001. H. = 6–6.5. G. = 3.1-3.2. F. = 7. Gelatinizes with HCl.

OPT. PROP.—The optic plane and positive acute bisectrix Z are normal to 010; X makes an angle of 26° to 30° with 001. The indices vary considerably with varying replacement of Mg by Fe and varying hydroxyl tenor. There are two types of chondrodite found in Sweden, one yellow, the other brown. The chemical differences between them are still unknown, but are perhaps chiefly in the state of oxidation of the iron, since the brown type is always decidedly altered and has higher relief.

	2V	N_g	N_m	N_p	$N_g - N_p$	$X \wedge 001$	
Yellow...	85°–90°	1.637	....	1.601	0.036	27° 12′	Barth[9]
	....	1.639 Na	1.619	1.607	0.032	30°±	Lacroix
	72° 14′ Na	1.643 Tl	1.620	1.607	0.036	26° 25′	Eckerman[10]
Brown...	72° 1′ Na	1.643 Tl	1.625	1.613	0.030	26° 34′	Eckerman[10]
	....	1.655 Na	1.632	1.621	0.034	31°	Eskola[11]

Very weak crossed dispersion, and also $\rho < v$, weak, in yellow chondrodite and $\rho < v$' weak, in the brown type.

Color light yellow, brownish red; in thin section the yellow type is colorless to brownish yellow and pleochroic with X = pale golden yellow or brownish yellow, Y = very pale yellow or colorless or pale yellowish green, Z = pale yellow or colorless or pale yellowish green, and $X > Z > Y$; the brown type has X and Y = reddish brown, Z = pale brown.

ALTER.—The brown type is more altered than the yellow; the product of alteration is antigorite, brucite, magnesite, etc.

OCCUR.—Contact mineral in limestone or dolomite; also in veins.

DIAG.—Differs in extinction angle from other humites; the twinning and color distinguish it from olivine.

HUMITE ORTHO. $a : b : c = 1.080 : 1 : 4.4034$ $Mg_5[Mg(F,OH)]_2(SiO_4)_3$

PHYS. CHAR.—Crystals small complex 100 or 001 tablets with 001 cleavage, not distinct in section. H. = 6. G. = 3.1. F. = 7. Gelatinizes with HCl.

[8] P. Geijer: *Geol. För. Förh. Stockholm*, XLVIII, 1926, p. 84; *Sver. Geol. Unders. Aarsb.* 20, 1926, No. 4, p. 16. This mineral was formerly known as *prolectite*.

[9] *Sær. Norsk Geol. Tids.*, VIII, 1924, p. 93.

[10] *Geol. För. Förh. Stockholm*, XLIV, 1922, p. 203.

[11] *Jour. Geol.*, XXX, 1922, p. 270.

Opt. Prop.—The optic plane and positive acute bisectrix Z are normal to 010; X is parallel with *a*.

2V	N_g	N_m	N_p	$N_g - N_p$	
(+) 67° 54′ $\rho > v$ weak	. . . .	1.643	. . . .	0.032-0.038	Lacroix
	1.652	1.624	1.617	0.035	Larsen

Color white, yellow, brown; in thin section colorless or pleochroic with X = pale golden yellow, Y = Z = very pale yellow to colorless, and X > Z > Y.

Alter.—Similar to chondrodite.

Occur.—A contact mineral in limestone or dolomite; also in veins.

Diag.—The extinction angle measured on the cleavage (or the lamellar twinning) in a section parallel to 010, that is, normal to Z, the acute bisectrix, is 0° in humite, 7°–12° in clinohumite, and 26°–30° in chondrodite. The lamellar twinning is not present in humite. Humites have the same colors as staurolite, but the golden yellow color is parallel to Z in the latter and parallel to X in humites. It is difficult to distinguish orthorhombic colorless humite from highly magnesian olivine without a test for fluorine, but in the former the optic angle is smaller, the refringence is less and the optic plane is parallel rather than normal to the best cleavage.

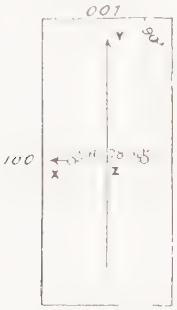


Fig. 150.—Optic orientation of humite.

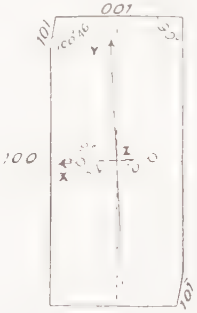


Fig. 151.—Optic orientation of clinohumite.

CLINOHUMITE Mono. $a : b : c = 1.0803 : 1 : 5.6588$ $\beta = 90°$ $Mg_7[Mg(F,OH)]_2(SiO_4)_4$

Phys. Char.—Crystals complex and varied with 001 cleavage, not prominent in sections. Lamellar twinning on 001. H. = 6. G. = 3.1. F. = 7. Gelatinizes with HCl.

Opt. Prop.—The optic plane and positive acute bisectrix Z are normal to 010; X makes an angle of 7° to 12.5° with 001. Weak crossed dispersion and $\rho > v$ very weak.

$$(+)\ 2V = 76°\ 27',\quad N_g = 1.690,\quad N_m = 1.670,\quad N_p = 1.658,\quad N_g - N_p = 0.032.$$

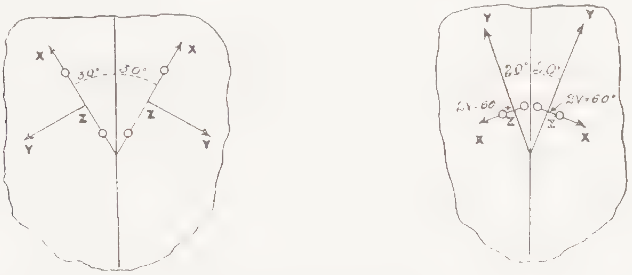
Color brown, yellow, white; in thin section colorless or pleochroic with X = pale golden yellow or brownish yellow, Y = very pale yellow or colorless or pale yellowish green, Z = pale yellow or colorless or pale yellowish green with X > Z > Y.

Alter.—Similar to chondrodite.

Occur.—A contact mineral in limestone;, also in veins; the various humites may occur together.

Diag.—See humite.

Titanclinohumite [7] is a titaniferous variety [12] with no distinct cleavage; but a parting on 001. Lamellar twinning on 103 or $\bar{1}03$, as also found in some clinohumite. H. = 6. G. = 3.25. F. = 7. Gelatinizes with HCl. $Z = b$; $X \wedge 001 = 7.5°$. (+) $2E = 110°$–$128°$ with $\rho < v$, strong. $N_g = 1.702$, $N_m = 1.678$, $N_p = 1.669$, $N_g - N_p = 0.033$. Color brownish red to yellow with X = deep reddish yellow to blood red, Y = Z = orange yellow and $X > Y > Z$. Found in talc schist and in serpentine. Rare.



Figs. 152, 153.—Optic orientation normal to Z in twinned chondrodite and titanclinohumite, respectively.

Hodgkinsonite $\{Mn(ZnOH)_2SiO_4\}$ is monoclinic with $a : b : c = 1.538 : 1 : 1.108$, $\beta = 84° \; 35'$; crystals pyramidal with perfect 001 cleavage. H. = 4.5-5. G. = 3.91. F. = easy after decrepitation. Gelatinizes with HCl. Optic plane is 010; Z emerges from cleavage plate. (−) 2V = moderate, $\rho > v$, distinct. $N_g = 1.75$, $N_m = 1.735$, $N_p = 1.715$, $N_g - N_p = 0.035$. Color pink to pale reddish brown. Found with willemite and franklinite at Franklin, N. J. Very rare.

Leucophenicite $\{Mn_5(MnOH)_2(SiO_4)_3\}$ is monoclinic with $a : b : c = 1.105 : 1 : 2.314$, $\beta = 76° \; 44'$; crystals elongated parallel to b, deeply striated; imperfect cleavage. Twinning on 001. H. = 5.5–6. G. = 3.85. F. = 3. Gelatinizes with HCl. The negative acute bisectrix X is normal to a cleavage. (−) $2V = 74°$, $\rho > v$ weak. $N_g = 1.782$–1.790, $N_m = 1.771$–1.778, $N_p = 1.751$–1.760, $N_g - N_p = 0.030 \pm$. Color pale purplish red; in section colorless or pale rose to colorless. Found with willemite and vesuvianite at Franklin, N. J. Very rare.

CUSPIDITE [13]	Mono.	$a : b : c = 0.724 : 1 : 1.934$	$\beta = 89° \; 22'$	$(CaF)_2SiO_3$
CUSTERITE [14]	Mono.	?		$[Ca(F,OH)]_2SiO_3$

Comp.—The two minerals are perhaps identical in composition.

Phys. Char.—Crystals small, pseudorhombic, with very good 001 cleavage. Distinct 110 cleavages are reported in custerite, the three directions being nearly at right angles. Lamellar twinning on 100 in cuspidite and on 001 in custerite. H. = 5–6. G. = 2.95–2.97 (cuspidite), 2.91 (custerite). F. = diff. Soluble in HNO_3.

[12] Formerly supposed to be a variety of olivine and then called *titanolivine*. Barth (*Sær. Norsk Geol. Tids.*, VIII, 1924, p. 93) has described a type apparently intermediate between titanclinohumite and chondrodite.

[13] F. S. Starrabba: *N. Jahrb. Mineral.*, 1914, I, p. 366.

[14] Umpleby, Schaller and Larsen: *Am. Jour. Sci.*, CLXXXVI, 1913, p. 385.

Opt. Prop.—Biaxial positive with large optic angle and $\rho > v$, marked. Optic orientation different; optic plane is 010 in cuspidite, and normal to 010 in custerite.

	2E	N_g	N_m	N_p	$N_g - N_p$	$Z \wedge c$	Color
Cuspidite..	110°	1.602	1.595	1.590	0.012	5.5°	Rose-red or colorless
Custerite..	105°	1.598	1.59	1.586	0.012	6.5°	Greenish gray to colorless

Cuspidite has marked inclined dispersion.

Occur.—Both are contact minerals associated with garnet, diopside, etc. Very rare.

Diag.—Moderate relief and birefringence, lamellar twinning with small (6°) maximum extinction angle, positive biaxial character with marked dispersion, $\rho > v$, and very good basal cleavage found in both. They differ, according to the descriptions, in optic orientation and direction of twinning.

CLINOHEDRITE Mono. $a : b : c = 0.682 : 1 : 0.323$ $\beta = 76° 2'$ $CaZn(OH)_2SiO_3$

Phys. Char.—Crystals varied, clinohedral, with perfect 010 cleavage. H. = 5.5. G. = 3.33. F. = 4 with exfoliation. Gelatinizes with HCl.

Opt. Prop.—The optic plane and obtuse bisectrix Z are normal to 010; $Y \wedge c = -28°$. (−) 2V = large. $N_m = 1.670$, $N_g - N_p = 0.01$. Colorless to white or amethystine.

Occur.—With willemite, garnet, etc., at Franklin, N. J. Very rare.

5. HYDROUS SILICATES OF DIVALENT BASES

Gyrolite ($H_2Ca_2Si_3O_9 \cdot H_2O$) is trigonal with $c = 1.936$. Formula also written $H_{10}Ca_4Si_6O_{21}$; tenor of water somewhat variable. Crystals lamellar with perfect 0001 cleavage. H. = 3–4. G. = 2.34–2.45. F. = difficult, with swelling. Soluble in acid. Uniaxial negative; also distinctly biaxial; basal sections divided into sectors. $N_o = 1.540$–1.548, $N_o - N_e = 0.01$ (Cornu [1]); $N_g = 1.532$, $N_m = 1.523$, $N_p = 1.518$, $N_g - N_p = 0.015$ (Müller [2]). Colorless, white. Found often with apophyllite from which it may be derived. Rare.

Reyerite is closely related to gyrolite, but contains less water and some alumina and soda. It has the same crystal form with G. = 2.5–2.55, and $N_o = 1.5645$, $N_e = 1.5590$, $N_o - N_e = 0.0055$. Colorless. Rare.

Zeophyllite ($3CaO \cdot CaF_2 \cdot 3SiO_2 \cdot 2H_2O$) is also trigonal with $c = 2.245$; perfect basal cleavage. H. = 3. G. = 2.76. F. = easy. Soluble in HCl. Uniaxial negative with $N_o = 1.565$, $N_e = 1.560$, $N_o - N_e = 0.005$. Also biaxial with 2V = 27°, as a maximum, with $\rho < v$. Colorless to greenish. Found with natrolite, etc., in amygdules. Very rare.

Xonotlite ($5CaSiO_3 \cdot H_2O$) is fibrous and orthorhombic (?) with perfect longitudinal cleavage, assumed to be 010. H. = 6.5. G. = 2.70. F. = 2.5. Soluble in HCl. Optic plane is 100 and Z = c (elongation). (+) 2V = very small, $N_g = 1.593$, $N_m = N_p = 1.583$, $N_g - N_p = 0.010$ (Larsen [3]). Other crystals [4] gave: $N_g = 1.590$, $N_p = 1.579$,

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[1] *Sitz. Akad. Wiss. Wien*, CXVI, 1907, p. 1213.

[2] *N. J. Min. Bl. Bd.*, XLIV, 1921, p. 402. Perhaps not gyrolite, since the indices given are apparently too low and make the mineral positive.

[3] E. S. Larsen: *Am. Jour. Sci.*, CXCIII, 1917, p. 464.

[4] W. F. Foshag and E. S. Larsen: *Am. Mineral.*, VII, 1922, p. 23; E. S. Larsen: *Am. Mineral.*, VIII, 1923, p. 181; E. V. Shannon: *Am. Mineral.*, X, 1925, p. 12; E. V. Shannon: *Proc. U. S. Nat. Mus.*, LXVI, 1925, Art. 28.

$N_g - N_p = 0.011$, and $N_g = 1.592$, $N_p = 1.580$, $N_g - N_p = 0.012$. Colorless to pink; color may fade on exposure to light. Found in limestone near igneous contacts. Rare.

Riversidite [5] ($2CaSiO_3 \cdot H_2O$) is fibrous and orthorhombic (?). H. = 3. G. = 2.61. F. = 2. Decomposed by HCl. $Z = c$ (elongation). Optic sign unknown. $N_g = 1.603$, $N_m = ?$, $N_p = 1.595$, $N_g - N_p = 0.008$. White. Found as veins in vesuvianite. Very rare.

Crestmorite [5] ($4CaSiO_3 \cdot 7H_2O$) is monoclinic with 100 (?) cleavage.[6] H.. = 3. G. = 2.22. F. = easy. Decomposed by HCl. $Z \wedge c$ (elongation) [6] = 12°. (−) 2V = large, $\rho > v$.[6] $N_g = 1.607$, $N_m = 1.603$, $N_p = 1.593$, $N_g - N_p = 0.014$ (Larsen). Color snow white. Found in blue calcite. Very rare.

Centrallasite [7] ($4CaO \cdot 7SiO_2 \cdot 5H_2O$?) is fibrous and orthorhombic (?). H. = 2.5. G. = 2.51. F. = easy. Soluble in HCl. X normal to platy cleavage. (−) 2V = small, $N_g = 1.549$, $N_m = 1.548$, $N_p = 1.535$, $N_g - N_p = 0.014$. Color white. Found in pegmatite, replacing quartz. Rare.

Foshagite [8] ($H_2Ca_5Si_3O_{12} \cdot 2H_2O$?) is orthorhombic and fibrous. H. = 3. G. = 2.36. Gelatinizes in HCl. $Z = c$. (+) 2V = very small, $N_g = 1.598$, $N_m = N_p = 1.594$, $N_g - N_p = 0.004$. Colorless. Associated with vesuvianite. Very rare.

Bementite [9] ($8MnO \cdot 7SiO_2 \cdot 5H_2O$?) is orthorhombic; crystals fibrous or lamellar with micaceous 001 and perfect 010 and 100 cleavages. H. = 6. G. = 3.1. F. = 3.5. Soluble in HCl. Acute bisectrix X normal to 001; Y or Z parallel to fibers. Nearly uniaxial. (−) 2E = nearly 0°, $N_g = N_m = 1.632$ to 1.650, $N_p = 1.602$ to 1.624, $N_g - N_p = 0.030$ to 0.026. Color brown, yellow, gray; darkens on weathering; pleochroism very weak with $X < Y = Z$. Found in anamorphosed manganese deposits, as at Franklin, N. J.

Bertrandite ($2Be_2SiO_4 \cdot H_2O$) is orthorhombic with $a : b : c = 0.569 : 1 : 0.597$. Formula also written $H_2Be_4Si_2O_9$; also $(BeOH)_2Be_2Si_2O_7$. Crystals basal or 010 plates of varied habit. Perfect 001 and good 100, 010 and 110 cleavages. Twinning common, on 011, 130, or 031. H. = 6. G. = 2.6. F. = 7. Insoluble in acids. The optic plane is 010; the negative acute bisectrix X is normal to 100. (−) 2V = 73°-75°, $N_g = 1.611$, $N_m = 1.603$, $N_p = 1.584$, $N_g - N_p = 0.027$ (Bowman [10]); $N_g = 1.614$, $N_m = 1.605$, $N_p = 1.591$, $N_g - N_p = 0.023$ (Vogt [11]).

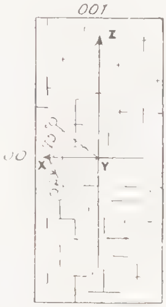

Fig. 154.—Optic orientation of bertrandite.

Colorless or stained (by limonite). Luster vitreous; pearly on 001.

Occur.—In pegmatite with beryl, herderite, tourmaline, quartz, etc.

Diag.—Differs from muscovite and some zeolites in that the best cleavage is normal to an obtuse bisectrix and this cleavage has negative elongation and parallel extinction; the crystal forms and pearly basal luster are also distinctive.

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[5] A. S. Eakle: *Bull. Dept. Geol. U. Calif.*, X, 1917, p. 327.

[6] E. E. Fairbanks: Private communication, April 20, 1926.

[7] W. F. Foshag: *Am. Mineral.*, IX, 1924, p. 88.

[8] A. S. Eakle: *Am. Mineral.*, X, 1925, p. 97.

[9] *Caryopilite* is the same. See *Jour. Wash. Acad. Sci.*, XI, 1921, p. 25. *Ectropite* of Flink (*Geol. För. Förh.*, XXXIX, 1917, p. 426) is considered the same as bementite by Larsen (*Am. Mineral.*, X, 1925, p. 418); he thinks it may be a manganese antigorite. It has: H. = 4, G. = 2.46, $N_g = N_m = 1.633$, $N_p = 1.608$.

[10] *Mineral Mag.*, XVI, 1911, p. 47.

[11] *Zeit. Kryst.*, L, 1911, p. 6.

CHRYSOTILITE (*Chrysotile*) ORTHORHOMBIC(?) $H_4Mg_3Si_2O_9$

Antigorite (of the chlorite group) and chrysotilite are probably dimorphous forms of the same compound.

PHYS. CHAR.—Usually fibrous; the fibers are separable and flexible in the variety known as *asbestus*. Indistinct 110 cleavages at 130°. H. = 2-3. G. = 2.36–2.5. F. = 6. Decomposed by HCl, leaving fibrous silica.

OPT. PROP.—The optic plane is 010 and the positive acute bisectrix Z is parallel to *c*, that is, the elongation. The optic angle is small and may appear to be zero on account of superposition of lamellæ of varying orientation.

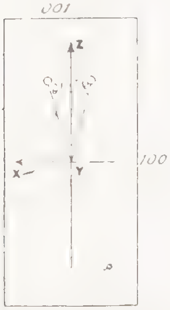

FIG. 155.—Optic orientation of chrysotilite

$(+)\ 2V = 30°–35°$, $N_g = 1.555$, $N_m = ?$, $N_p = 1.542$, $N_g - N_p = 0.013$.

Larsen also reports much lower indices (the higher indices found in thin sections being explained as due to loss of water on heating in making the section), as follows: $(+)\ 2V =$ large, $N_g = 1.522$, $N_m = 1.512$, $N_p = 1.508$, $N_g - N_p = 0.014$.

Color green, golden yellow, gray. In thin section pale greenish or yellow to colorless; in thicker sections distinctly pleochroic with X = Y = greenish yellow to colorless, Z = green or yellow.

OCCUR.—Commonly associated with antigorite in serpentine rocks; also in veins in such rocks; less commonly as a decomposition product of ferromagnesian minerals in various other rocks.

DIAG.—Differs from antigorite by the sign of the acute bisectrix, the small optic angle, and somewhat stronger birefringence; also by fibrous rather than lamellar structure. Distinguished from fibrous amphiboles by much weaker birefringence, lower relief and parallel extinction.

Xylotilite (*Xylotile*) is a ferriferous chrysotilite in which the iron is partly oxidized to the ferric state. G. = 2.56 (green type); 2.4 (brown type). Fusible. Decomposed by HCl. The positive acute bisectrix Z is parallel to *c* or the elongation of the fibers, as in chrysotilite. $(+)\ 2E = 20°\pm$. $N = 1.57\pm$, $N_g - N_p = 0.026\pm$. Color green or brown, strongly pleochroic in section with X = Y = pale yellowish, Z = very dark golden yellow. Found in serpentine and crystalline limestone. Rare. Differs from chrysotilite by darker color and intense pleochroism, as well as stronger birefringence. Differs from bowlingite just as chrysotilite differs from antigorite.

Deweylite (*Gymnite*—$H_{12}Mg_4Si_3O_{10}$) is orthorhombic (?). Gum-like masses, microscopically fibrous; may be spherulitic. H. = 2-3.5. G. = 2.2–2.4. F. = 6 with decrepitation. Slowly attacked by HCl. Axis Z parallel to fibers. $(+)\ 2E =$ small. $N_m =$

1.505–1.525 (with[12] 4.2 NiO). $N_g - N_p = .01 \pm$. Color white, yellow, reddish, green. Found in veins in serpentine and in crystalline limestone. Rare. The microstructure distinguishes deweylite from chrysotilite; the former has lower refringence than quartz.

Garnierite is a nickeliferous deweylite of uncertain formula; Ni replaces Mg in any amount, both H_2O and SiO_2 seem to be variable. Mammillary masses, microscopically fibrous to spherulitic like chalcedony. Surface is earthy, or smooth like talc (variety *nouméite*). H. = 1–3. G. = 2.27–2.87, varying with tenor of Ni. F. = 7. Decomposed by HCl. Nouméite has the axis Z parallel to fibers. (+) 2E = very small, N = 1.59?, $N_g - N_p$ = weak. Garnierite is cryptocrystalline or amorphous and isotropic with N = 1.59. Color dark green (nouméite), apple green (garnierite), rarely yellowish; in thin section bright green, rarely yellowish. The chief nickel ore in serpentine in New Caledonia, associated with chromite, steatite, etc. Also found in Pennsylvania, Oregon, North Carolina, etc. Differs from deweylite and chrysotilite by bright green color, chalcedonic to amorphous texture and presence of nickel.

TALC ORTHORHOMBIC OR MONOCLINIC $H_2Mg_4(SiO_3)_5 \cdot H_2O(?)$

COMP.—Part of the water is supposed to be held along basal cleavage planes by electrostatic attraction.[13] The formula is often written $H_2Mg_3(SiO_3)_4$.

PHYS. CHAR—Compact foliated masses; with perfect 001 cleavage, the laminæ being flexible and somewhat elastic. Percussion figure as in micas, but with the lines normal to 010, 110 and $1\bar{1}0$. Twinning rare, producing pseudocubic forms. H. = 1. G. = 2.7–2.8. Insoluble. F. = 6, after whitening due to exfoliation. Half of the water is lost below dull red heat; the rest is lost rapidly between 875° and 960° C. Changes to enstatite(?) at red heat with N = 1.664.

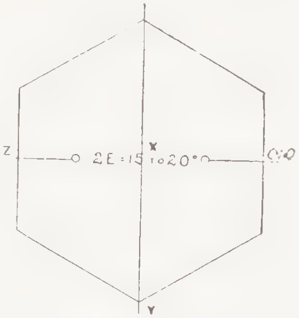

FIG. 156.—Optic orientation of talc.

OPT. PROP.—The optic plane is 100; the negative acute bisectrix X is nearly or quite normal to 001. The optic angle may seem to be 0°, due to superposition of laminæ of varying orientation.

(−) $2V = 0°$ to $30°$, $\rho > v$; $N_g = 1.575–1.590$, $N_m = ?$, $N_p = 1.538–1.545$, $N_g - N_p = 0.030–0.050$.

After losing half its water content the mineral has practically the same optic properties.

Color pale green, white, greenish gray to dark green, reddish by alteration; colorless in thin section.

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[12] C. S. Ross and E. V. Shannon: *Am. Mineral.*, X, 1925, p. 444.

[13] W. F. Foshag and E. T. Wherry: *Am. Mineral.*, VII, 1922, p. 167.

Occur.—Most abundant in certain schists where it may form rock masses (known as *soapstone* or *steatite*) with minor amounts of other minerals such as tremolite, chlorite, magnetite, etc. Also in some serpentine, chlorite schist, dolomite, etc. An unusual alteration product of olivine, enstatite, etc., in igneous rocks.

Diag.—Differs from pyrophyllite and muscovite in its small optic angle; from brucite in its sign and biaxial character as well as insolubility; not readily distinguished from sericite, but the indices of refraction are somewhat lower.

SEPIOLITE Orthorhombic(?) $H_4Mg_2Si_3O_{10}$

Comp.—The tenor of H_2O varies greatly with aqueous vapor pressure; the formula is written in several other ways, for example, $MgSiO_3 \cdot H_2SiO_3 \cdot nH_2O$.

Phys. Char.—Always finely fibrous; commonly mixed with apparently amorphous material of the same or very similar composition, the mixture constituting the substance called *meerschaum*. H. = 2–2.5. G. = 2. Dry porous masses float on water. F. = 6, in most cases after blackening, giving a burnt smell and turning white. Sepiolite does not and *parasepiolite* does gelatinize with HCl.

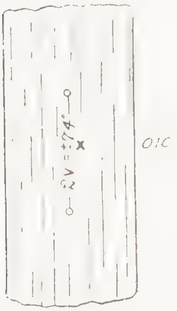

Fig. 157.—Optic orientation of sepiolite.

Opt. Prop.—The axis Z is parallel to the elongation (*c*) of the fibers. Optic angle small, and may appear to be 0°.

(−) 2V = 0°–50° (74°?), N_g = 1.525 1.529, N_m = ?, N_p = 1.515–1.520, $N_g - N_p = 0.009 \pm$.

Parasepiolite has: (−) 2V = 50°, N_m = 1.506, $N_g - N_p$ = 0.011.

By heating above 100° C., N_g becomes 1.535 ±. The apparently amorphous part of *meerschaum*, called β-sepiolite, has N = 1.517 ±.

Color white, pink, greenish, pale yellow. More transparent after immersion in liquid. Colorless in thin section, but may be pleochroic in thick sections with X = colorless to very pale yellow, Y = Z = golden yellow.

Incl.—Inclusions may be abundant, of calcite or dolomite with or without silica. In Morocco there may be a little potassium and magnesium sulphate as inclusions.

Occur.—In serpentine as an alteration product; associated with opal.

Diag.—Meerschaum is compact with a smooth feel. Sepiolite is much like kaolinite and fine sericite, but has lower refringence.

Planchéite[14] ($2CuSiO_3 \cdot H_2O$?) is orthorhombic; fibrous masses or spherulites. H. = 5.5. G. = 3.27–3.36. F. = 7. Difficultly attacked by HCl without gelatinization. Optic plane and X appear to be normal to a cleavage; Z parallel to elongation. (+) 2V = medium. N_g = 1.715 (1.73 Gaubert[14]), N_m = 1.660, N_p = 1.645, $N_g - N_p$ = 0.070. May appear uniaxial, probably due to interwoven fibers; then N_g = 1.697, N_p = 1.640, $N_g - N_p$ = 0.057. Isotropic fibers are also known with N = 1.678. Color pale to dark blue with X and Y = colorless and Z = blue. Found with dioptasite, malachite, cuprite, calcite, etc., in copper deposits in Africa. Unknown elsewhere.

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[14] A. Lacroix: *Bull. Soc. Min. Fr.*, XXXI, 1908, p. 250. W. T. Schaller: *Jour. Wash. Acad. Sci.*, V, 1915, p. 7, and IX, 1919, p. 131. F. Zambonini: *Comp. Rend.*, CLXVI, 1918, p. 495. M. Henglein: *Zeit. prak. Geol.*, XXIX, 1921, p. 53. A. Schoep: *Ann. Soc. Geol. Belg.* annex to vol. XLIV, 1922, p. C 11. H. Buttgenbach: *Mem. Acad. R. Belg. Cl. Sci.*, VII, 1923.

CHRYSOCOLLA ORTHORHOMBIC? $CuSiO_3 \cdot H_2O$?

PHYS. CHAR.—Very finely fibrous like chalcedony; conchoidal fracture. H. = 2 ±. G. = 2.4 ±. F. = 7, but turns black. Attacked by acids.

OPT. PROP.—Uniaxial positive with $N_o = 1.46$, $N_e = 1.54$, $N_e - N_o = 0.08$ according to Umpleby[15]; also uniaxial positive with $N_o = 1.40$, $N_e - N_o$ = moderate; also biaxial negative with $N_g = 1.598$, $N_m = 1.597$, $N_p = 1.575$, $N_g - N_p = 0.023$, 2V = small; also of unknown sign with positive elongation and $N_g = 1.635$, $N_p = 1.585$, the indices being apparently much lower until the pores are filled, according to Larsen.[16] The data are very discordant—probably several minerals present. Color green, blue; also brown to black when impure with iron oxides. Faintly pleochroic with X = pale bluish green and Z = colorless.

OCCUR.—In the oxide zone of copper deposits in siliceous rocks.

Bisbeeite ($CuSiO_3 \cdot H_2O$) is orthorhombic; crystals thin laths. H. = soft. Optic plane normal to laths with Z parallel to elongation. (+) 2V = small, $N_g = 1.71$, $N_m = 1.625$, $N_p = 1.615$, $N_g - N_p = 0.095$. Color pale blue to nearly white and cottonlike. In thick section, X and Y = colorless to pale olive brown, Z = colorless to pale green, and Z > Y and X. Found as an alteration product of shattuckite in copper deposits in Arizona.

Shattuckite[17] ($2CuSiO_3 \cdot H_2O$?) is monoclinic in fibrous masses pseudomorphous after malachite. G. = 3.79. Optic plane and X normal to 010; $Z \wedge c$ (elongation) = small. (+) 2V = large, $N_g = 1.815$, $N_m = 1.782$, $N_p = 1.752$, $N_g - N_p = 0.063$ (Larsen); $N_g = 1.796$, N_m = ?, $N_p = 1.730$, $N_g - N_p = 0.066$ (Schaller). Color light to dark blue, greenish; pleochroic with X = very pale blue, Y = pale (greenish) blue, Z = deep (greenish) blue. Found with malachite at Shattuck copper mine at Bisbee, Ariz.

Afwillite[18] ($3CaO \cdot 2SiO_2 \cdot 3H_2O$) is monoclinic with $a : b : c = 2.097 : 1 : 2.381$, $\beta = 81° 34'$. Crystals elongated parallel to b with perfect 001 and imperfect 100 cleavages. H. = 4. G. = 2.63. F. = difficult. Soluble in HCl. Optic plane is 010; $X \wedge c = +30.6°$ (with 31.2° red, 29.9° blue). (+) 2V = 54° 40′, $\rho < v$. $N_g = 1.6336$ Na, $N_m = 1.6204$, $N_p = 1.6169$, $N_g - N_p = 0.0167$. Colorless. Found in a diamond mine in South Africa. Very rare.

Jurupaite[19] $\{(Ca,Mg)_2Si_2O_6 \cdot H_2O\}$ is monoclinic (?) in radiating compact fibrous masses with H. = 4 across fibers. G. = 2.75. F. = 2. Soluble in HCl. Axis Z makes an angle of 31° with c (elongation). Optic sign is positive, optic angle unknown. $N_g = 1.576$, N_m = ?, $N_p = 1.568$, $N_g - N_p = 0.007$. Color white. Found in bluish calcite with grossularite in the Jurupa Mountains, Calif.

Okenite[20] ($CaSiO_3 \cdot H_2SiO_3 \cdot H_2O$) is triclinic with $\alpha = 122° 54'$, $\beta = 67° 46'$, $\gamma = 50° 10'$; fibrous interlaced masses; also small 010 laths elongated parallel to c with perfect 010 cleavage, appearing curved in aggregates; twinning on 010 and axis c. Elastic. H. = 5. G. = 2.28–2.33. F. = 2.5. Gelatinizes with HCl. Extinction parallel to c in 010, but oblique in all other directions; thus, for light moving parallel to 010 and normal to c, the extinction is at 30°–34° to c, and for light traveling parallel to c, the extinction is at 25° to the 010 cleavage. (−?) $2V$ = large, $N_g = 1.541$, $N_m = ?$, $N_p = 1.530$, $N_g - N_p = 0.01$. Color white or pale tinted. Colorless in section. Found in amygdules in basalt with apophyllite, heulandite, etc. Among fibrous minerals okenite has the highest refringence, with parallel extinction in single crystals lying on 010, but oblique extinction in aggregates, and positive elongation.

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[15] *U. S. G. S. Prof. Paper* 97, 1917, p. 51. N_o also given as 1.57 by same author in *Jour. Wash. Acad. Sci.*, IV, 1914, p. 181.

[16] *U. S. G. S. Bull.* 679, 1921, pp. 185, 253, 280.

[17] W. T. Schaller: *Jour. Wash. Acad. Sci.*, V, 1915, p. 7, and IX, 1919, p. 131. F. Zambonini: *Comp. Rend.*, CLXVI, 1918, p. 495.

[18] John Perry and F. E. Wright: *Mineral. Mag.*, XX, 1925, p. 277.

[19] A. S. Eakle: *Am. Mineral.*, VI, 1921, p. 107.

[20] O. B. Böggild: *Kgl. Danske Vid. Selskab. Math. fys. Meddel.*, IV, 1922, No. 8.

Inesite $\{2(Mn,Ca)SiO_3 \cdot H_2O\}$ is triclinic with $a : b : c = 0.975 : 1 : 1.321$, $\alpha = 92° 18'$, $\beta = 132° 56'$, $\gamma = 93° 51'$. Crystals prismatic to fibrous, radiated, with perfect 010 and good 100 cleavages. H. = 6. G. = 3.03. F. = 3. Decomposed by HCl. Axis X nearly normal to 010, extinction on 010 $(Z' \wedge c) = 60°$ in acute angle β; extinction on 100 $(Y' \wedge 010) = 10°–12°$ in obtuse angle α. Section 100 gives Z on edge of field. (−) $2V = 60°$, $\rho > v$, $N_g = 1.644$, $N_m = 1.636$, $N_p = 1.609$, $N_g - N_p = 0.035$ (Larsen); $N_p = 1.618$, $N_g - N_p = 0.026$ (Ulrich [21]). Color rose to flesh-red; weakly pleochroic. Found in manganese deposits in Germany and Sweden. Rare.

Cornuite $(mCuO \cdot nSiO_2 \cdot H_2O)$ is an opaline or enamel-like gel in coatings. H. = 2. G. = 2 ±. F. = 7. More soluble in HCl than chrysocolla. Conchoidal fracture. Isotropic with $N = 1.525–1.55$, average about 1.54. May have irregular weak birefringence with wavy extinction (due to strain?). Crystallization produces fibrous chrysocolla; also, probably dioptasite, etc. Color bluish green, blue; brown to black, when impure. Found in the oxide zone of copper deposits in siliceous rocks.

Spadaite $(5MgO \cdot 6SiO_2 \cdot 4H_2O?)$ is apparently amorphous with H. = 2.5. F. = 4. Gelatinizes with HCl. Isotropic with $N = 1.53 \pm$. Color reddish; luster pearly or greasy. Colorless in section. Found with wollastonite in lava. Very rare.

Neotocite $(MnSiO_3 \cdot nH_2O?)$ is apparently amorphous with H. = 4. G. = 2.7. F. = difficult. Attacked by acid. Isotropic with $N = 1.53$ to 1.56 ($1.47 \pm$?). Color black, coal-like; brown in powder. Found in ore deposits. Very rare.

Greenalite $(FeSiO_3 \cdot nH_2O?)$ is apparently amorphous; often contains some ferric iron and a little Mg; it is related to glauconite and chamosite. G. = 2.8 +. Soluble in HCl. Isotropic with [22] $N = 1.650–1.654$. Color green, to yellow or brown from alteration. In thin section green, yellow, brown, black; in reflected light green and yellow granules appear dark green or yellow; brown and black granules appear light green. Abundant in the Lake Superior region in cherts; on the Mesabi range the chief constituent of the rock called taconite.

6. ANHYDROUS SILICATES OF TRIVALENT BASES

Eulytite $(Bi_4Si_3O_{12})$ is isometric; crystals tetrahedral, minute, with poor 110 cleavage. H. = 4.5. G. = 6.1. F. = 2. Gelatinizes with HCl. Isotropic with $N = 2.05$. Color brown, yellow, gray. Also weakly birefringent, uniaxial negative with $N_o = 2.05$, $N_o - N_e$ = very weak. Found with native bismuth or quartz in Saxony. Very rare.

Bazzite (silicate of scandium, etc.) is hexagonal and barrel-shaped. H. = 6.5. G. = 2.8. F. = 7, but turns dark. Insoluble except in HF. Uniaxial negative with $N_o = 1.626$, $N_e = 1.608$, $N_o - N_e = 0.018$ in the interior, and $N_o = 1.623$, $N_e = 1.602$, $N_o - N_e = 0.021$ in outer zone. Color bright azure blue with X = intense azure blue, Z = very pale greenish yellow. Found in a geode in granite in Italy. Very rare.

Yttrialite $\{(Y,Th)_2Si_2O_7\}$ is pseudo-orthorhombic, prismatic, perhaps an alteration product of thalenite. H. = 5.5. G. = 4.58. F. = 7. Soluble in HCl. Isotropic with $N = 1.758$. Color black, brown, olive green; pale green in section. Found in pegmatite. Very rare.

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[21] *Min. Abst.*, II, 1924, p. 352.

[22] As measured by J. E. Hawley at the University of Wisconsin, 1925.

SILLIMANITE ORTHORHOMBIC $a : b : c = 0.97 : 1 : 1.34$ Al_2SiO_5

PHYS. CHAR.—Crystals nearly square long prisms, vertically striated; terminal faces rare. Perfect 010 cleavage. H. = 7.5. G. = 3.25. F. = 1816° C. Insoluble.

OPT. PROP.—The plane of the optic axes is parallel to 010, or the cleavage plane. The positive acute bisectrix Z is parallel to *c*, the elongation. The relief is marked and the birefringence rather strong. The optic angle is small and somewhat variable, with $\rho > v$, strong. (+) $2V = 30°–25°$, $N_g = 1.677–1.684$, $N_m = 1.658–1.660$, $N_p = 1.657–1.661$, $N_g - N_p = 0.020–0.023$.

There is a slight variation[1] in index with change of color, but contrary to the usual rule, the darker the color the lower the index. Thus, in a dark-brown crystal from Saybrook, Hlawatsch found: $N_g = 1.6773$ and $N_p = 1.6549$, while in a pale-brown variety: $N_g = 1.6837$ and $N_p = 1.6612$.

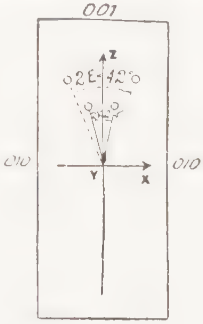

FIG. 158.—Optic orientation of sillimanite.

Colorless, yellowish, greenish, brown, blue; the brown color may be due to scales of biotite in some cases. Colorless in thin section; in thick sections:

X = pale brownish	brownish yellow	very pale yellow
Y = brown	grayish green	colorless or greenish
Z = dark brown	violet blue	sapphire blue

INVER.—Sillimanite seems to be stable at all temperatures below about 1545° C. It dissociates into $3Al_2O_3 \cdot 2SiO_2$ (*mullite*) and liquid at about 1545° C. If heated above 1810° C., it dissociates to Al_2O_3 (corundum) and liquid.

INCL.—Natural sillimanite often contains inclusions of spinel or biotite or glass.

OCCUR.—Most abundant in crystalline schists, gneisses and similar rocks; also found in eclogite, and about contacts, especially of granite. It is formed in igneous rocks probably only as a result of absorption of shales, etc.

DIAG.—Differs from zoisite and andalusite by the positive elongation, rather strong birefringence, and optic plane parallel to cleavage. Interlacing needles are characteristic of the variety called *fibrolite*.

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[1] A fibrous variety (*fibrolite* or *bucholzite*) is reported to have decidedly lower indices in some cases, for example, $N_g = 1.635 \pm$, $N_p = 1.629$ (Shannon: *Proc. U. S. Nat. Mus.*, LVIII, 1920, p. 437).

ANDALUSITE Orthorhombic $a:b:c = 0.986:1:0.703$ Al_2SiO_5

Phys. Char.—Crystals nearly square prisms with good 110 cleavages at 90° 48′. H. = 7.5. G. = 3.1–3.2. F. = 7. Insoluble.

Opt. Prop.—The optic plane is parallel to 010; the negative acute bisectrix X is normal to 001. Optic angle large with $\rho < v$ weak.

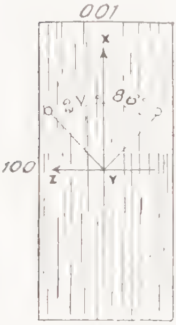

Fig. 159.—Optic orientation of andalusite.

	Finland [2]	Brazil [3]—Red	Brazil [4]—Yellow
$(-)\ 2V =$	83° 6′	84°	85°
$N_g =$	1.6390	1.6440	1.647
$N_m =$	1.6328	1.6390	1.644
$N_p =$	1.6290	1.6326	1.640
$N_g - N_p =$	0.0100	0.0114	0.007

Color red, violet, gray, yellow, green; through alteration may be brown, gray, green, black Pleochroism variable in intensity even in a single crystal. Colorless in thin section; in thick section:

X = colorless	pale yellow	olive green	greenish yellow
Y = colorless	pale yellow	oil green	deep green
Z = rose red	rose red	blood red	yellow

Inver.—Changes to mullite and glass at temperatures above 1300° C.

Incl.—Carbonaceous inclusions are characteristic of the variety called *chiastolite*; they are commonly concentrated in the crystal in shapes conforming to the symmetry of the crystal.

Alter.—Changes rather easily to sericite; also, rarely, to a mixture of corundum and spinel with rutile and feldspar.

Occur.—Confined chiefly to contacts of igneous rocks and shaly material.

Diag.—Distinguished by its nearly rectangular prismatic forms parallel to prismatic cleavage with negative sign and negative elongation. Carbonaceous inclusions are common.

Manganandalusite or *viridine* [5] $\{(Al,Mn,Fe)_2SiO_5\}$ differs from ordinary andalusite, not only in containing some manganese (iron and titanium), but also in optic properties. It has good 110 cleavages with H. = 6.5 and G. = 3.22. The optic plane is 010, and $X = a$. $(+)\ 2V = 71°$, $\rho < v$, $N_g = 1.691$, $N_m = 1.671$, $N_p = 1.662$, $N_g - N_p = 0.029$. Color dark green; pleochroic even in thin section with X = clear yellow, Y = grass green, Z = dark yellow. Found in hornfels near Darmstadt, and in Sweden.

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[2] E. Mäkinen: *Bull. Com. Geol. Finlande*, No. 35, 1913, p. 42.

[3] E. Taubert: *Inaug. Diss. Jena*, 1905, *Zt. Kr.*, XLIV, 1908, p. 313.

[4] E. A. Wülfing: *Sitz. Akad. Wiss. Heidelberg, Math-nat. Kl. Abt. A.*, 12, 1917.

[5] H. Bäckström: *Geol. För. Förh.*, XVIII, 1896, p. 386; *Zeit. Kryst.*, LVI, 1922, p. 628.

MULLITE[6] ORTHORHOMBIC $a : b : c = 0.986 : 1 : ?$ $Al_6Si_2O_{13}$

PHYS. CHAR.—Crystals prismatic with vertical elongation and distinct 010 cleavage. G. = 3.03.

OPT. PROP.—The optic plane is 010 and $Z = c$. (+) $2V = 45°$ to $50°$, $N_g = 1.654$, $N_m = 1.644$, $N_p = 1.642$, $N_g - N_p = 0.012$. Color lilac-pink to colorless with X = Y = colorless and Z = rose-pink. May take Fe_2O_3 or TiO_2 in crystal solution with consequent increase of indices. For example, natural crystals from the island of Mull with $Fe_2O_3 = 0.50$, $TiO_2 = 0.79$ have $N_g = 1.668$, $N_p = 1.651$, $N_g - N_p = 0.017$; artificial crystals with $Fe_2O_3 = 0.86$ and $TiO_2 = 1.12$ have: $N_g = 1.672$, $N_p = 1.653$, $N_g - N_p = 0.019$; and unanalyzed crystals have $N_g = 1.682$, $N_p = 1.661$, $N_g - N_p = 0.021$, overlapping the properties of sillimanite.

OCCUR.—In phyllite xenoliths in igneous intrusions. Rare in nature; very common in porcelain, etc., being the only compound of Al_2O_3 and SiO_2 stable at high temperature.

TOPAZ ORTH. $a : b : c = 0.528 : 1 : 0.954$ $Al(F,OH)_2AlSiO_4$

PHYS. CHAR.—Crystals usually prismatic, often vertically striated, with very perfect 001 cleavage. H. = 8. G. = 3.52–3.57, increasing with tenor of F. F. = 7. Only slightly attacked by H_2SO_4.

OPT. PROP.—The optic plane is parallel to 010; the positive acute bisectrix Z is normal to 001, the perfect cleavage. (+) $2V = 65°–48°$, $\rho > v$ distinct. The optic properties vary with the tenor of hydroxyl as shown below (sodium light).

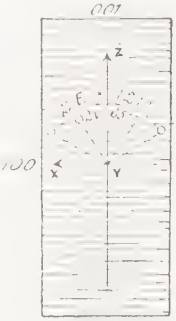

FIG. 160.—Optic orientation of topaz.

	Utah	Adun Tschalon	Saxony [5]	Schneckenstein	Bohemia [7]	Japan	Minas Geraes	Urals [8]
H_2O =	0.19	0.58	0.73	0.93	1.28	1.83	2.45	?
(+) 2E =	125° 53′	118° 46′	117° 48′	114° 28′	116° 12′	119° 30′	84° 28′	84° 50′
N_g =	1.6176	1.6225	1.6215	1.6250	1.6243	1.6229	1.6375	1.6379
N_m =	1.6104	1.6160	1.6147	1.6181	......	1.6155	1.6308	1.6308
N_p =	1.6072	1.6133	1.6121	1.6155	1.6147	1.6123	1.6294	1.6293
$N_g - N_p$ =	0.0104	0.0092	0.0094	0.0095	0.0096	0.0106	0.0081	0.0086
G =	3.565	3.562	3.568	3.555	3.547	3.537	3.532	3.549

Colorless, yellow, gray, greenish, bluish, reddish. Colorless in thin section. Colored crystals in thick plates are pleochroic, with, for example: X = brownish yellow, Y = yellowish pink, Z = violet pink.

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[6] N. L. Bowen, J. W. Greig and E. G. Zies: *Jour. Wash. Acad. Sci.*, XIV, 1924, p. 183. Mullite is said to be merely $2Al_2SiO_5 + Al_2O_3$, that is, extremely fine corundum in fibrous sillimanite by W. Eitel: *Zeit. Kryst.*, LXIV, 1927, p. 535.

[7] V. Rosicky: *Min. Abst.*, I, 1922, p. 338.

[8] R. C. Sabot: *Thèse* 519, *U. Genève*, 1914; *Zeit. Kryst.*, LVI, 1922, p. 631.

Incl.—Liquid inclusions common; they have been regarded as water or carbon dioxide; in some cases a carbide of hydrogen is reported. These liquids may contain minute crystals of unknown composition. Other inclusions include ilmenite and hematite.

Alter.—Topaz may alter to kaolinite or sericite.

Occur.—Especially in contact zones and pegmatite, commonly associated with cassiterite, fluorite, tourmaline, beryl, etc.

Diag.—Differs from andalusite by its cleavage and smaller optic angle, from sillimanite by weaker birefringence and different cleavage direction; massive topaz differs from feldspar in higher relief and density, scarcity of twinning and parallel extinction.

Törnebohmite[9] $\{(Ce,La,Al)_3(F,OH)(SiO_4)_2\}$ is biaxial granular with H. = 4.5. G. = 4.9. (+) 2E = 49°, $\rho < v$, very strong. $N_m = 1.81 \pm$, $N_g - N_p = 0.028–0.030$, $N_m - N_p = 0.001 \pm$ (Geijer). $N_g = 1.878$, $N_m = 1.852$, $N_p = 1.845$, $N_g - N_p = 0.033$ (quoted by Larsen). Color bright olive green with X = pink to greenish yellow, Y = bluish green, Z = clear pink, and $X = Z < Y$. Found in contact zones in Sweden. Very rare.

Thortveitite[10] $\{(Sc,Y)_2Si_2O_7\}$ is monoclinic with $a : b : c = 0.767 : 1 : 0.557$ and $\beta = 77° 28'$. Crystals tapering with good 110 cleavages, 001 parting, and twinning on 110. H. = 6–7. G. = 3.49–3.57. F. = diff. Insoluble in HCl. Optic plane is 010; $X \wedge c = +5°$. (–) 2V = 66° (50°), $N_g = 1.8093$ (1.803), $N_m = 1.7926$, $N_p = 1.7561$, $N_g - N_p = 0.0532$. Color grayish green; pleochroic in thick sections with X = deep green, Y and Z = yellow. Found in pegmatite in Norway and Madagascar. Very rare.

Thalenite[11] $(Y_2Si_2O_7)$ is monoclinic with $a : b : c = 0.919 : 1 : 0.648$, $\beta = 82° 55'$. Crystals 110 tablets or prismatic, with no cleavage. H. = 6.5. G. = 4.23–4.45. Optic plane and Z normal to 010; $Y \wedge c = -1°$ to $-3°$. (–) 2V = 67° 35' (73°, $\rho < v$ weak, Vogt[12]). $N_g = 1.7436$, $N_m = 1.7375$, $N_p = 1.7312$ Na, $N_g - N_p = 0.0124$. Crystals may be zonal with $N_g - N_p$ as low as 0.007 in the central part. Color pink. Found in pegmatite in Sweden. Very rare.

Agricolite $(Bi_4Si_3O_{12})$ is monoclinic and fibrous. H. = 3? G. = 6. F. = 2. Gelatinizes with acid. Optic orientation unknown. (+?) 2V = large, $N_m = 1.99–2.03$, $N_g - N_p$ = weak. Color yellow to brown. Found with bismuth on quartz. Very rare.

CYANITE (*Disthene*) Tric. $a : b : c = 0.899 : 1 : 0.709$ Al_2SiO_5

$\alpha = 90° 23'$ $\beta = 100° 18'$ $\gamma = 106° 1'$

Phys. Char.—Crystals 100 tablets elongated parallel to *c*; terminations rare. Perfect 100 and good 010 cleavages; 001 parting.

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[9] P. Geijer: *Sver. Geol. Unders. Aarsbok*, XIV, 1920, No. 6.

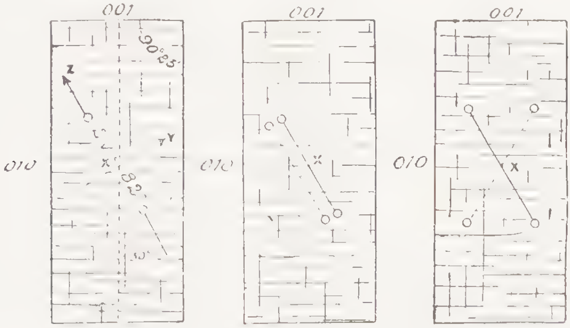
[10] J. Schetelig: *Cent. Min.*, 1911, p. 721; 1912, p. 64; also A. Lacroix: *Comp. Rend.*, CLXXI, 1920, p. 421. *Minéral. Madag.*, I, 1922, p. 500, and J. Schetelig: *Norsk Geol. Tidsskr.*, VI, 1922, p. 233. See also: *Vid. Skr. I Mat. nat. Kl.*, 1922, No. 1, pp. 40 and 51.

[11] H. Sjögren: *Geol. För. Förh. Stockholm*, XXVIII, 1906, p. 93.

[12] *Vid. Skr. I Mat. nat. Kl.*, 1922, No. 1, p. 19.

Twinning often lamellar with 100 as composition face, and twinning axis either normal to 100 or parallel to *b* or *c*; also multiple twinning on 001 may be produced by pressure. Crystals distinctly flexible and often bent or twisted. H. on 100 = 4–5 parallel to *c* and 6–7 parallel to *b*; on 010 H. = 7; on $1\bar{1}0$, H. = 7.5. G. = 3.6 ±. F. = 7. Insoluble.

Opt. Prop.—The negative acute bisectrix X is nearly normal to 100; extinction on 100, $Z' \wedge c = 27°–32°$, extinction on 010, $Z' \wedge c = 5°–8°$; extinction on 001, $X' \wedge a = 0°–2.5°$. (−) $2V = 82.5° \pm$, $\rho > v$, weak, with weak inclined and distinct crossed dispersion; $N_g = 1.728$ D, $N_m = 1.722$, $N_p = 1.713$, $N_g - N_p = 0.015$ (Taubert [3]); $N_g = 1.729$ Na, $N_m = 1.722$, $N_p = 1.717$, $N_g - N_p = 0.012$ (Wülfing [13]).



Figs. 161–163.—Optic orientation of cyanite.

Color blue, white, rarely gray, green, black. Colorless in thin section; but in plates 0.5 to 1 mm. thick may be pleochroic with X = colorless, Y = violet blue, Z = dark cobalt blue. Color disappears on heating.

Inver.—Changes slowly (but more easily than andalusite) to mullite and glass at temperatures above 1300° C.

Alter.—Alters readily to muscovite sometimes with chlorite.

Occur.—Only in schists and pegmatites cutting schists.

Diag.—Distinguished by numerous cleavage lines, high relief, moderate birefringence, and extinction at about 30° to 010 cleavage in sections normal to the acute bisectrix X; this extinction direction is at about 60° to the basal parting.

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[13] E. A. Wülfing: *Mikr. Phys.*, I, 2, 1905, p. 378.

7. HYDROUS SILICATES OF TRIVALENT BASES

Zunyite $\{Al_6(OH,F,Cl)_8Si_2O_{15}\}$ is isometric; crystals tetrahedral with 111 cleavages. H. = 7. G. = 2.87. F. = 7, but becomes opaque. Insoluble in acids. Isotropic with N = 1.589 (Larsen); 1.602 (Albis [1]); 1.595 (Gossner and Mussgnug [2]). Colorless. Found in a lead deposit in Colorado. Very rare.

Kochite [3] ($2Al_2O_3 \cdot 3SiO_2 \cdot 5H_2O$?) is isometric in cubic crystals with G. = 2.93. Isotropic with N = 1.59. Colorless. Found in Japan. Very rare.

PYROPHYLLITE ORTHORHOMBIC(?) $H_2Al_2Si_4O_{12}$

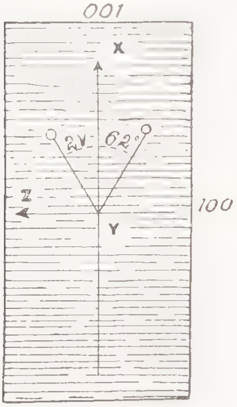

FIG. 164.—Optic orientation of pyrophyllite.

PHYS. CHAR.—Lamellar masses or fibrous with perfect 001 cleavage giving flexible, inelastic laminæ. H. = 1-1.5. G. = 2.66-2.9. F. = 6, after much increase of volume. Partly decomposed by HCl.

OPT. PROP.—Axis X normal to 001 (cleavage) and Z parallel to elongation of blades. (−) 2V = 53°-60°, $\rho > v$, weak; $N_g = 1.600$, $N_m = 1.588$, $N_p = 1.552$, $N_g - N_p = 0.048$. Colorless or tinted.

OCCUR.—Abundant in some schists, as in North Carolina. Used to make slate pencils.

DIAG.—Differs from talc and muscovite by larger optic angle and from kaolinite by much stronger birefringence.

KAOLIN GROUP

The minerals of the kaolin group are hydrous silicates of iron, aluminum or chromium; they are pseudohexagonal and probably monoclinic but crystallization is poor and lamellar. The following are included: [4]

Nontronite (Chloropal)	Green	$H_4Fe_2Si_2O_9$
Faratsihite	Yellow	$H_4(Al,Fe)_2Si_2O_9$
Kaolinite	White	$H_4Al_2Si_2O_9$
Miloschite	Blue	$H_4(Al,Cr)_2Si_2O_9$
Volchonskoite	Green	$H_4Cr_2Si_2O_9$

NONTRONITE (*Chloropal*) MONOCLINIC(?) $H_4Fe_2Si_2O_9$

COMP.—The tenor of water is variable and often more than $2H_2O$.

PHYS. CHAR.—Compact, resembling opal; also earthy. Perfect 001 cleavage; poor 110 cleavages at about 63°. Feel soapy to meager. Soft. G. = 2.5. F. = 7. Gelatinizes with HCl.

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[1] *Min. Abst.*, II, 1923, p. 43.

[2] *Cent. Min.*, 1926, A, p. 155.

[3] S. Kozu *et al.*: *Min. Abst.*, II, 1923, p. 51.

[4] E. T. Wherry and G. V. Brown: *Am. Mineral.*, I, 1916, p. 63.

Opt. Prop.—The negative acute bisectrix X is (nearly?) normal to 001 and Z is (nearly?) parallel to elongation of fibers. Optic properties vary (through alteration?) as follows:

2V	N_g	N_m	N_p	N_g-N_p	X	Y	Z
Small	1.585	1.585	1.560	0.025	Pale yellow	Olive green	Yellow to bright green
Large	1.600	1.590	1.580	0.020	Orange (yellowish)	Orange-yellow	Yellow to bright green
?	1.620	1.61	1.595	0.025	Yellow-green	Yellow-green	Brown- to olive-green
Small	.....	1.645	.....	0.03	Yellow to brown with X > Z		
33°	1.655	1.65	1.625	0.03	Nearly colorless	Yellow to greenish yellow	

Also reported as: (+) 2V = large, $N_g = 1.625$, $N_m = 1.62$, $N_p = 1.610$, $N_g - N_p = 0.015$, with X = yellow-brown and Z = pale yellow.

Color dark olive green to yellow or orange, greenish yellow. Pleochroic in yellow, green, brown, as given above.

Occur.—An alteration product in veins and rocks. Rare.

Faratsihite [5] $\{H_4(Al,Fe)_2Si_2O_9\}$ is a ferriferous kaolinite; lamellar, soft. G. = 2 +. F. = diff. Decomposed by HCl. Biaxial negative with slightly greater birefringence than kaolinite. $N_m = 1.56$ (Larsen), but variable. $N_g - N_p = 0.02 \pm$. Positive elongation. Color yellow. Found as an alteration product in Madagascar. Rare.

KAOLINITE Monoclinic $H_4Al_2Si_2O_9$

$a : b : c = 0.575 : 1 : 1.600 \quad \beta = 83° 11'$

Phys. Char.—Crystals pseudohexagonal basal scales with twinning as in mica. Compact with greasy feel. Perfect 001 cleavage, laminæ flexible, not elastic. H. = 2 2.5. G. = 2.6 2.63. F. = 7. Insoluble in acids. Loses water at about 450° C.

Opt. Prop.—The optic plane and obtuse bisectrix Z are normal to 010; the axis Y makes an angle [6] of (+) 11° with a (001 cleavage) in the obtuse angle β. This angle is distinctly larger in red than in violet light. Optic angle large. (−) 2V = 60°, $\rho > v$ weak. $N_g = 1.567$, $N_m = 1.565$, $N_p = 1.561$, $N_g - N_p = 0.006–0.007$.

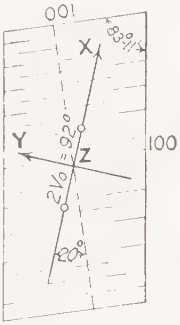

Fig. 165.—Optic orientation of kaolinite.

Dick [7] reports finding optically positive kaolinite with 2V = 68° and Y ∧ 001 = 15°–20°. He calls the negative type *nacrite*. The indices reported by

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[5] A. Lacroix: *Bull. Soc. Fr. Min.*, XXXVII, 1914, p. 231: *Minéral. Madagascar*, I, 1922, p. 495.

[6] A. Johnsen: *Cent. Mineral.*, 1911, p. 33.

[7] A. B. Dick: *Mineral. Mag.*, XV, 1909, p. 124.

Schaller [8] ($N_g = 1.567$, $N_m = 1.563$, $N_p = 1.561$) on an intumescent variety also indicate a positive sign.

Colorless, white, rarely tinted (by impurities). Luster pearly on 001.

Inver.—Artificially several forms [9] of "kaolinite" minus H_2O, that is, $H_2Al_2Si_2O_8$, are known, but their stability relations and optic properties are unknown.

Occur.—A common alteration product of feldspar, nephelite, scapolite, and other silicates. Formed by surface waters, and also by hot ascending solutions. Clay usually contains some quartz, limonite, etc., as well as kaolinite.

Diag.—Differs from sericite, talc, pyrophyllite, and gibbsite by its weak birefringence, inclined extinction and infusibility.

Miloschite $\{H_4(Al,Cr)_2Si_2O_9\}$ is a chromiferous kaolinite, lamellar to tabular. H. = 2.5. G. = 2.1. F. = 7. Almost insoluble in HCl. Basal cleavage. Extinction slightly inclined. (−) $2V = 90° \pm$, $N_g = 1.559$, $N_m = 1.556$, $N_p = 1.552$, $N_g - N_p = 0.007$. Color pale greenish blue; in section bluish green, not pleochroic. Produced by weathering of hydrothermal minerals, especially fuchsite. Very rare.

Volchonskoite ($H_4Cr_2Si_2O_9$) is monoclinic (?), lamellar. H. = 2.5. G. = 2.2–2.3. F. = 7, but blackens. Gelatinizes with HCl. Nearly always contains some Fe and Al replacing Cr. $N_m = 1.585$, $N_g - N_p$ = moderate. Color bluish to grass green. Found in clay. Very rare.

Halloysite ($Al_2O_3 \cdot 2SiO_2 \cdot nH_2O$?) is apparently amorphous. H. = 1–2. G. = 2.0–2.2. F. = 7. Insoluble. Isotropic with $N = 1.47 \pm$ (with 25 per cent H_2O) to 1.555 (dried at 60° C.) Larsen;[10] $N = 1.54$ (with 23 per cent H_2O) to 1.57 (with 17.8 per cent H_2O).[11] After ignition, $N = 1.540$–1.595. The variety *indianaite* [12] has $N = 1.538$. Color white or tinted. Common in beds and veins as a constituent of clay.

Montmorillonite ($Al_2O_3 \cdot 2SiO_2 \cdot nH_2O$?) is apparently amorphous to microcrystalline. Soft. G. = 2 ±. F. = 7. Isotropic (in large part) with $N = 1.49$ (McLintock [13]), 1.50 (Splichal [11]), 1.55 (Larsen [10]). May become anisotropic [14] with $N_g - N_p$ = very weak to 0.02. After ignition $N = 1.51$ to 1.53. Color white, pink, bluish, green. An alteration product of feldspar, spodumenite, etc. *Collyrite* is closely related in composition; it is isotropic with $N = 1.555$. Rare.

Allophanite (*Allophane*—$Al_2O_3 \cdot SiO_2 \cdot nH_2O$?) is apparently amorphous. H. = 3. G. = 1.85–1.89. F. = 7. Gelatinizes with HCl. Isotropic with $N = 1.47$–1.49. After ignition,[11] $N = 1.50$–1.57. Color blue, green, brown to white, the color due to impurities. Forms hyaline crusts and masses in deposits of copper and limonite, and in beds of coal.

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[8] W. T. Schaller and R. K. Bailey: *Jour. Wash. Acad. Sci.*, VI, 1916, p. 67.

[9] S. Weyberg: *Trav. Mus. Geol. Acad. Sci. Petrograd*, 1911, 5, p. 57.

[10] E. S. Larsen: *U. S. Geol. Surv. Bull.* 679, 1921, pp. 172, 173, 174.

[11] J. Splichal: *Mineral. Abst.*, I, 1922, p. 288.

[12] A. F. Rogers: *Jour. Geol.*, XXV, 1917, p. 535.

[13] *Mineral. Mag.*, XX, 1923, p. 143.

[14] H. Leitmeier: *Zeit. Kryst.*, LV, 1915, p. 353.

Schroetterite ($3Al_2O \cdot SiO_2 \cdot nH_2O$?) is apparently amorphous. H. = 3–3.5. G. = 2 ±. Isotropic with N = 1.584. Color white, green, brownish. Like opal or gum. Found in clay and limestone. Rare.

Termierite ($Al_2O_3 \cdot 6SiO_2 \cdot 18H_2O$?) is apparently amorphous and clay-like. H. = 2. G. = 1.2(?). F. = 6. Slowly soluble in HCl. Isotropic with N = 1.403, or weakly birefringent ($N_g - N_p = 0.002$) perhaps due to strain. Found with kaolinite in antimony deposits. Very rare.

Alumina-silica hydrogels are apparently amorphous and isotropic with N = 1.48 to 1.68 after ignition, decreasing with increasing silica, thus:—If $Al_2O_3 : SiO_2 = 1 : 0$, N = 1.68; 1 : 0.9, N = 1.58–1.595; 1 : 1.9, N = 1.535–1.545; 1 : 2.8, N = 1.520–1.535; 1 : 4.3, N = 1.495–1.505; 1 : 6.5, N = 1.48–1.49; 0 : 1, N = 1.48–1.485 (Splichal[11]). The determination of the refractive index of the colloidal constituent of clays and laterites would determine whether the alumina is present as a hydrate or as a silicate.

Hisingerite ($Fe_2O_3 \cdot 2SiO_2 \cdot nH_2O$?) is apparently amorphous with conchoidal fracture. H. = 3–3.5. G. = 3. F. = 6. Decomposed by HCl. Isotropic with N = 1.59 ±, index higher than balsam[15]; 1.49–1.53, (Larsen); 1.45–1.47 (Hawkins and Shannon[16]); 1.57 and 1.66 (Schaller[17]). Also finely crystalline in fibrous aggregates with (−) 2V = 0° to small. Black or brownish black with yellowish brown streak, but may be claret red for a few minutes after fresh fracture underground. Found in ore deposits as an alteration product. Rare.

Canbyite[15] ($Fe_2O_3 \cdot 2SiO_2 \cdot 4H_2O$) is perhaps the crystalline equivalent of hisingerite. Obtuse bisectrix Z normal to cleavage. (−) 2V = small; $N_g = 1.582$, $N_m = 1.580$, $N_p = 1.562$, $N_g - N_p = 0.020$. N_m also varies from 1.552 to 1.595 for an unknown reason. Color golden to amber brown and not pleochroic. Found in a contact(?) deposit in Delaware. Rare.

8. SILICATES OF DIVALENT AND MONOVALENT BASES

APOPHYLLITE TETRAGONAL $c = 1.25 \pm$ $4CaSiO_3 \cdot H_2SiO_3 \cdot KSiO_2(F,OH) \cdot nH_2O$?

COMP.—Formula very uncertain; Groth writes it $H_7KCa_4Si_8O_{24} \cdot 4.5H_2O$, ignoring the F. About half the water is lost at about 250° C., the rest at higher temperatures.

PHYS. CHAR.—Crystals prismatic with 001 or 111. Rare twinning on 111. Perfect 001 and imperfect 110 cleavages. H. = 4.5–5. G. = 2.3–2.4. F. = 1.5, with exfoliation. Slimy silica with HCl.

OPT. PROP.—Uniaxial and positive or, less commonly, negative; in some cases basal sections are divided into sectors some of which are biaxial, positive for red and negative for blue, with axial planes crossed as in brookite; the biaxial character may be produced by lateral pressure or changes of temperature in some cases. Strikingly abnormal interference colors and interference figures due to marked dispersion of the birefringence, which may be zero in any part of the spectrum, the corresponding color then being absent in the interference tints. The abnormal colors may disappear at about 275° C., which suggests that they are due to part of the water. Cornu[1] reports that apophyllite with F is negative, has lower refringence, and, if biaxial, the dispersion is $\rho > v$, while apophyllite without F is positive, has higher refringence, and, if biaxial, the dispersion is $\rho < v$, but these conclusions need verification, and are opposed in part by the data of Wenzel,[2] who found that isotropic and negative apophyllites have higher refringence than positive types.

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[15] P. P. Sustschinsky: *Zeit. Kryst.*, XLVII, 1910, p. 231.

[16] *Am. Mineral.*, IX, 1924, p. 1.

[17] *Am. Jour. Sci.*, CCX, 1925, p. 29.

[1] F. Cornu: *Cent. Mineral.*, 1906, p. 79.

[2] A. Wenzel: *N. Jahrb. Min. Beil. Bd.*, XLI, 1916, p. 565.

	Positive			Isotropic (Na)			Negative		
	N_o	N_e	N_e-N_o	N_o	N_e	N_e-N_o	N_o	N_e	N_o-N_e
Li =	1.532	1.534	0.002	1.5381	1.5384	0.0003	1.5415	1.5415	0.0000
Na =	1.535	1.537	0.002	1.5418	1.5418	0.0000	1.5433	1.5429	0.0004
Tl =	1.537	1.539	0.002	1.5438	1.5438	0.0000	1.5448	1.5439	0.0009

Colorless, white or tinted. Colorless and clear in thin section.

Alter.—A cloudy alteration product may be calcite or a kaolinite-like substance.

Occur.—In cavities in basaltic rocks, or, less commonly, in granite or gneiss, often associated with zeolites. Also an alteration product of wollastonite produced at contacts.

Diag.—Apophyllite has a higher refringence than common in zeolites; it differs from uniaxial zeolites in having a perfect basal cleavage. The tetragonal form and abnormal interference colors are also quite characteristic.

Meliphanite ($NaCa_2Be_2FSi_3O_{10}$) is tetragonal with $c = 0.658$; crystals obtuse pyramidal; also platy, with distinct 001 cleavage. H. = 5–5.5. G. = 3.0. Fuses with intumescence. Insoluble. Uniaxial negative with $N_o = 1.6126$, $N_e = 1.5934$, $N_o - N_e = 0.0192$; also slightly biaxial, with $(-)\ 2E = 36°$ (max.). Color yellow; rarely reddish from alteration. In thick plates X = greenish yellow, Z = honey to brownish yellow, and $X < Z$. Found in pegmatite in syenite in Norway. Very rare.

EUDIALITE Trigonal $c = 2.11$ $Na_{13}(CaCl)(Ca,Fe)_5(Si,Zr)_{20}O_{52}$?
EUCOLITE Trigonal $c = 2.1 \pm$ $Na_4(CaCl)(CeOH,Ca,Fe)_7(Si,Zr)_{16}O_{41}$?

Comp.—Formulas very uncertain, but there is clearly considerable variation in Ce, and some in Si and Na.

Phys. Char.—Crystals varied with distinct 0001 cleavage. H. = 5–6. G. = 2.8–3.1. F. = 2.5. Gelatinizes with HCl.

Opt. Prop.—Uniaxial positive (eudialite) or negative (eucolite). An intermediate type is sensibly isotropic. Also slightly biaxial, 2E (variable in a single crystal) reaching 50°.

	Eudialite	Intermediate	Eucolite[3]
$N_o =$	$1.608 \pm$ to 1.610	$1.607 \pm$	1.620 to 1.643
$N_e =$	$1.610 \pm$ to 1.613	$1.607 \pm$	1.618 to $1.634 \pm$
$N_e - N_o =$	0.001 to 0.004	0.000	$N_o - N_e = 0.001$ to $0.010 \pm$

Zonal crystals of eucolite from Madagascar vary in birefringence from zero to 0.009.

Color pale pink, carmine, red, brown. In thin section usually colorless, but very variable even in a single crystal; in thick section a = yellow to colorless, c = carmine to bright yellow and $a < c$, independent of the optic sign.

Occur.—In nephelite syenite and granite. Very rare.

Diag.—The pleochroism, weak birefringence and association with soda minerals are distinctive. Differs from birefringent garnet in lower refringence.

Leucophanite $\{Na(BeF)CaSi_2O_6\}$ is orthorhombic with $a : b : c = 0.994 : 1 : 0.672$. Crystals commonly 001 tablets with perfect 001 and distinct 100 and 010 cleavages. Twinning frequent on 110 or 001, often interpenetrated. Crystals pseudotetragonal, resembling meliphanite closely. H. = 4. G. = 2.96. F. = 6 with intumescence. Insoluble. The optic plane is 100; X = *c*. (−) 2E = 74°; 2V = 39°, $\rho > v$, $N_g = 1.598$, $N_m = 1.595$, $N_p = 1.571$, $N_g - N_p = 0.027$. Color white, green, yellow; colorless in section. Found in pegmatite in Norway. Very rare.

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[3] A. Lacroix: *Bull. Soc. Fr. Min.*, XXXVIII, 1915, p. 278; *Minéral. Madagascar*, I, 1922, p. 588.

ASTROPHYLLITE Orth. $a : b : c = 0.990 : 1 : 4.710$ $(K,Na)_4(Fe,Mn)_4(Si,Ti,Zr)_5O_{16}$?

Phys. Char.—Crystals elongated parallel to *c*, or 010 plates elongated parallel to *a*. Perfect 010 and imperfect 001 cleavages; laminæ brittle. H. = 3. G. = 3.3–3.4. F. = 3 with swelling. Decomposed by HCl leaving scaly silica.

Opt. Prop.—The optic plane is 001; Z = *a*. (+) 2V = 75°±, $\rho > v$ (also reported as negative with 2V = 88° 10′ by Böggild[4]), $N_g = 1.733$, $N_m = 1.703$, $N_p = 1.678$, $N_g - N_p = 0.055$.

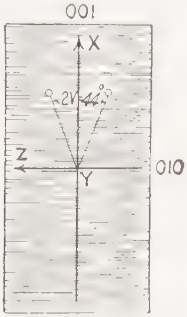

Fig. 166.—Optic orientation of leucophanite.

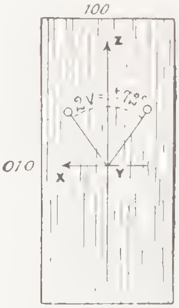

Fig. 167.—Optic orientation of astrophyllite.

Color bronze to gold yellow. Luster submetallic, pearly. Strongly pleochroic with X > Y > Z in astrophyllite, and X = Y < Z in a mineral, otherwise very similar, called *lamprophyllite* in which[4a] (+) 2V = 40°, $N_m = 1.75$, $N_g - N_p = 0.033$–0.040; the pleochroic colors are:

	Astrophyllite	Lamprophyllite
X =	dark golden yellow, reddish brown	straw yellow
Y =	orange yellow, yellowish brown	straw yellow
Z =	lemon yellow, paler yellowish brown	gold yellow

Occur.—Only in nephelite syenite and soda granite. Very rare.

Diag.—Astrophyllite differs from mica in having brittle laminæ, the obtuse bisectrix normal to the cleavage and maximum absorption normal to the lamellæ.

Epididymite ($HNaBeSi_3O_8$) is orthorhombic with $a : b : c = 0.576 : 1 : 0.534$. Crystals 001 plates, either hexagonal in outline or elongated parallel to *a*. Twinning on 001 with revolution of 60°. Perfect 001 and 010 cleavages. H. = 5.5. G. = 2.548. F. = 3. Nearly insoluble in acid. The optic plane[5] is 001; Z = *b*. (+) 2V = 22.5° Na, $\rho > v$; $N_g = 1.546$, $N_m = 1.544$, $N_p = 1.544$, $N_g - N_p = 0.002$. Colorless. Found in pegmatite in Greenland. Very rare.

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[4] O. B. Böggild: *Med. Grön.* XXXIII, 1906, p. 97; *N. Jahrb. Min.*, 1910, I, p. 362.

[4a] A. E. Fersman: *Am. Mineral.*, XI, 1926, p. 289.

[5] G. Flink: *Med. Grön.*, XXIV, 1901, p. 70.

Eudidymite ($HNaBeSi_3O_8$) is monoclinic with $a : b : c = 1.711 : 1 : 1.107$, $\beta = 86° 14'$. Crystals 001 plates with constant lamellar twinning on 001. Perfect 001 and imperfect $\bar{5}51$ cleavages. H. = 6. G. = 2.55. F. = 3. Nearly insoluble. The optic plane is 010; $Z \wedge c = -58.5°$. (+) 2V = 29° 55′ Na, $\rho > v$ distinct. $N_g = 1.551$, $N_m = 1.546$, $N_p = 1.545$, $N_g - N_p = 0.006$. Colorless. Found in cavities in zircon syenite in Norway. Very rare.

Leucosphenite ($Na_4BaTi_2Si_{10}O_{27}$) is monoclinic with $a : b : c = 0.581 : 1 : 0.850$, $\beta = 86° 37'$. Crystals vertically elongated or 001 plates. Often twinned on 001, with distinct 010 cleavage. H. = 6.5. G. = 3.05. F. = diff. Decomposed by HF. The optic plane is normal to 010; $Y \wedge c = +3°$, $X \wedge a = 0.5°$. (+) 2V = 77°, $\rho > v$, distinct. $N_g = 1.688$, $N_m = 1.661$, $N_p = 1.645$, $N_g - N_p = 0.043$ (Flink); $N_g = 1.684$, $N_m = 1.657$, $N_p = 1.640$, $N_g - N_p = 0.044$ (Larsen). Color white. Found in Greenland. Very rare.

Neptunite[6] $\{(Na,K)_2(Fe,Mn)(Si,Ti)_5O_{12}\}$ is monoclinic with $a : b : c = 1.316 : 1 : 0.080$, $\beta = 64° 22'$. Crystals prismatic, varied, with perfect 110 cleavages at 80°. H. = 5–6. G. = 3.19. F. = 2.5 to black globule. Insoluble in HCl. Optic plane is 010; $Z \wedge c = +16°$ to $+ 20°$. (+) 2V = 49°, $\rho < v$, extreme, $N_g = 1.736$, $N_m = 1.700$, $N_p = 1.690$, $N_g - N_p = 0.046$. Color black; deep red in splinters; X = pale yellow, Y = yellowish red, Z = deep ochre yellow to brownish red. Found in nephelite syenite in Greenland, Russia and California. Rare.

Molengraafite is a monoclinic titanosilicate of Ca and Na with some Al. Crystals prismatic with perfect 100 cleavage. Multiple twinning on 100 common. Optic plane normal to 010; $Z \wedge c$ = very small; $Y \wedge a$ = small. (+) 2V = 28°, $N_g = 1.770$, $N_m = 1.74$, $N_p = 1.735$, $N_g - N_p = 0.035$. Color yellow to gray with X = light yellow, Y = colorless, Z = straw yellow. Found in a rare igneous rock. Very rare.

PECTOLITE MONOCLINIC $HNaCa_2Si_3O_9$

$a : b : c = 1.114 : 1 : 0.986$ $\beta = 84° 46'$

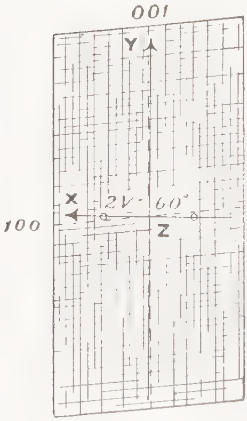

FIG. 168.—Optic orientation of pectolite.

PHYS. CHAR.—Crystals often elongated parallel to b; twinning on 100. Perfect 100 and 001 cleavages. H. = 4.5–5. G. = 2.74–2.88. F. = 2. Attacked by HCl.

OPT. PROP.—The optic plane and Z are normal to 010; $X \wedge a$ = small. Elongation positive. (+) 2V = 60°, $\rho > v$ weak, $N_g = 1.633$, $N_m = 1.606$, $N_p = 1.595$, $N_g - N_p = 0.038$. A sample from Kola[6a] has: (+) 2V = 53°, $N_g = 1.643$, $N_m = 1.642$, $N_p = 1.610$, $N_g - N_p = 0.033$. Colorless.

OCCUR.—In cavities or seams in igneous or metamorphic rocks.

ALTER.—An apparently amorphous alteration product of pectolite known as *stevensite* is isotropic with N = 1.50 ±; the formula is $H_2Mg_3(SiO_3)_4 \cdot H_2O$, nearly the same as talc.

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[6] Gossner argues (*Cent. Min.*, 1925, A., p. 73) that neptunite is chemically and physically closely related to pyroxenes.

[6a] A. E. Fersman: *Am. Mineral.*, XI, 1926, p. 289. The indices indicate a negative sign.

DIAG.—Distinguished from wollastonite by positive elongation and greater birefringence.

Manganpectolite with 4 per cent MnO has been described from Magnet Cove, Ark. The optic angle is small (2E = 15°) and the dispersion ($\rho > v$) is very strong, as in titanite. Rare.

Magnesiopectolite [7] with 5 per cent MgO has G. = 2.69; optic plane parallel to fibers which have negative elongation. (+) 2V = ?, $N_m = 1.56 \pm$, $N_g - N_p = 0.04 \pm$. Colorless. Rare.

Rosenbuschite $\{Na_2Ca_3(Si,Ti,Zr)_4O_{12}\}$ is monoclinic with $a : b : c = 1.169 : 1 : 0.957$, $\beta = 78° 13'$. Fluorine commonly present; also manganese and cerium. Crystals prismatic or acicular with perfect 001 and indistinct 100 and $\bar{2}01$ cleavages. H. = 5–6. G. = 3.3. F. = easy. Soluble in HCl. The optic plane and X are normal to 010; $Z \wedge c = -13°$. (+) 2V = 60°±, $N_g = 1.711$, $N_m = 1.687$, $N_p = 1.682$, $N_g - N_p = 0.029$. Color orange or gray; weak pleochroism in section in pale yellow with X < Y < Z. Found in nephelite syenite. Very rare.

Laavenite is a monoclinic zircono-silicate of Ca, Mn, Na with some Ti, Ta, F, OH. $a : b : c = 1.066 : 1 : 0.715$, $\beta = 69° 42'$. Crystals prismatic or 100 tablets with distinct 100 cleavage. Lamellar twinning on 100. H. = 6. G. = 3.5. Slowly soluble in HCl. Optic plane is 010; $X \wedge c = -20°$. (−) 2V = 80°, dispersion weak. $N_m = 1.750$, $N_g - N_p = 0.030$. Color yellow, brown or colorless; may have X = colorless to clear wine yellow, Y = colorless to greenish yellow, Z = golden or brownish yellow to orange-red. Found in nephelite syenite. Very rare.

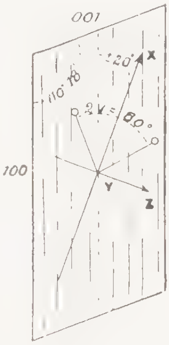

FIG. 169.—Optic orientation of laavenite.

Schizolite $\{HNa(Ca,Mn)_2Si_3O_9\}$ is triclinic; $a : b : c = 1.106 : 1 : 1.986$, $\alpha = 90° 11'$, $\beta = 94° 46'$, $\gamma = 103° 7'$. Crystals similar to those of pectolite; perfect 100 and 001 cleavages. H. = 5–5.5. G. = 2.97–3.13. The axis Z is near b; $Y \wedge a = 9°$. Positive elongation. (+) 2E = 82° 40′, $\rho < v$ distinct. $N_g = 1.660$, $N_m = 1.636$, $N_p = 1.631$, $N_g - N_p = 0.029$. Color light red altering to brown. Found in nephelite syenite in Greenland. Very rare.

9. SILICATES OF BORON (AND, OR) RARE EARTHS AND ONE OR MORE OTHER BASES

Rowlandite $\{Fe(Y,Ce,La)_2(YF)_2Si_4O_{14}\}$ is isotropic but crystals are unknown; fracture conchoidal. H. = 6–7. G. = 4.5. F. = 7. Gelatinizes with HCl. Isotropic with N = 1.725. Color drab-green to red; pale green in section. Found with gadolinite in Texas. Very rare.

Beckelite $\{Ca_5(Ce,La,Di)_4Si_3O_{15}\}$ is isometric, cubic or dodecahedral, with cubic cleavage. H. = 5. G. = 4.15. F. = 7. Soluble in acid. Isotropic with N = 1.812. Large crystals weakly birefringent. Color yellow to brown. Found in nephelite syenite in Russia. Very rare.

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[7] E. Reuning: *Cent. Min.*, 1907, p. 739.

TOURMALINE TRIGONAL $c = 0.44–0.45$ R_6SiO_5?

COMP.—Tourmaline is a complex boro-silicate of aluminum with other bases, varying considerably in composition, with ditrigonal symmetry. In spite of much study the formulas of the several end-compounds are still uncertain; according to Kunitz[1] the three chief types have the following formulas:

Lithium tourmaline	$H_5NaLi_2Al_2Al_8B_4Si_8O_{41}$	(*Elbaite*)
Iron tourmaline	$H_5NaFe_2Fe_2Al_8B_4Si_8O_{41}$	(*Schorlite*)
Magnesium tourmaline	$H_5NaMg_2Mg_2Al_8B_4Si_8O_{41}$	(*Dravite*)

There is probably a continuous series from elbaite to schorlite and from schorlite to dravite. Kunitz reports also a series from elbaite to a manganese tourmaline. Further, these minerals can vary by increase of alumina, for example, to $H_5NaMg_2Al_{10}B_4Si_8O_{42}$. This has very little effect upon the optic properties. Finally, some types of tourmaline contain some chromium, others titanium, and still others ferric iron.

PHYS. CHAR.—Crystals usually prismatic, vertically elongated and vertically striated; also lenticular; at times hemimorphism very distinct. Radiating groups common. Twinning rare. Difficult $11\bar{2}0$ and $10\bar{1}1$ cleavages. H. = 7–7.5. G. = 2.9–3.2. Dravite fuses at about 4 to a white or gray blebby glass; schorlite fuses at about 5.5 to a dark slag; elbaite is usually infusible. Insoluble even in HF. After fusion gelatinizes with HCl.

OPT. PROP.—Tourmaline is uniaxial and negative, but in some cases it is slightly biaxial, 2E reaching about 10°. The refringence is medium and the birefringence moderate to strong. Of the three chief types schorlite (iron tourmaline) has the highest refringence and strongest birefringence. Data follow.

Pure elbaite: $N_o = 1.6401$, $N_e = 1.6202$, $N_o - N_e = 0.0199$ (Kunitz)
Pure schorlite: $N_o = 1.698$, $N_e = 1.658$, $N_o - N_e = 0.040$ (extrapolated)
Pure dravite: $N_o = 1.6350$, $N_e = 1.6144$ $N_o - N_e = 0.0206$.

	Schorlite				Dravite	
	Average*	Approximate range			Average*	Range
	All	Black	Blue	Green		
$N_o=$	1.668	1.65 –1.69	1.652–1.665	1.64 –1.67	1.650	1.63–1.655
$N_e=$	1.639	1.63 –1.66	1.628–1.637	1.62 –1.65	1.628	1.61–1.63
$N_o-N_e=$	0.029	0.025–0.035	0.024–0.030	0.026–0.034	0.022	0.02–0.025
G.=			3.14–3.21	3.12–3.22		3.03–3.10

*P. Reiner: *Inaug. Diss. Heidelberg*, 1913, p. 49. C. Doelter: *Handb. Mineralchemie*, II, 2, 1917, p. 782.

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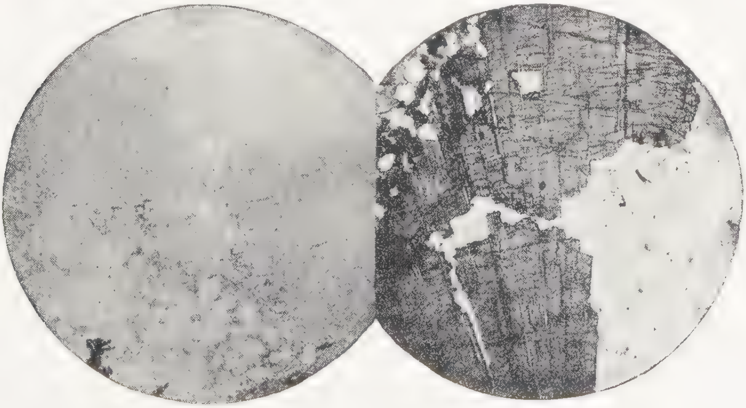
[1] *Cent. Min.*, 1926, A, p. 376.

	Elbaite		Special types with		
	Average *	Range	$CaO = 4.10$	$Cr_2O_3 = 10.86$	$Fe_2O_3 = 6.68$
$N_o =$	1.646	1.635-1.65	1.641	1.687	1.692
$N_e =$	1.625	1.615-1.63	1.626	1.641	1.657
$N_o - N_e =$	0.021	0.015-0.023	0.015	0.046	0.035
G. =	....	3.01-3.13	3.05	3.12	3.2

* P. Reiner: *Inaug. Diss. Heidelberg*, 1913, p. 49. C. Doelter: *Handb. Mineralchemie*, II, 2, 1917, p. 782.

Color black, bluish black, dark brown, less commonly blue, green, red, pink, colorless. Single crystals may vary in color. Pleochroism quite variable in intensity, but the absorption is always $X < Z$, or $O > E$. Therefore the maximum absorption occurs when the vertical axis (and elongation) is at right angles to the vibration plane of the polarizer. Examples of pleochroic formulas follow:

	X(E)	Z(O)
	Sections 1.5 mm. thick	
Elbaite	colorless or nearly so	pink, pale green, greenish blue
Dravite	pale yellow	dark yellowish brown
	Sections .03 mm. thick	
Elbaite	colorless	colorless, pink, pale blue
Dravite	colorless	pale yellow
Schorlite	pale to dark yellow	yellowish brown to black
Schorlite	reddish violet, brownish	dark green
Schorlite	pale violet gray, yellowish	blue of various shades
Cr-tourmaline	yellow	green to bluish green



FIGS. 170, 171.—Photomicrographs of tourmaline in thin section showing strong absorption.

A single crystal may have different colors in zones or irregularly distributed or at opposite ends of the vertical axis.

Incl.—Very intense pleochroic colors may be present about inclusions of zircon or rutile; the halos often differ in color from the enclosing mineral and disappear upon heating; in them the birefringence is increased.

Alter.—Usually unaltered, but may change to sericite, often with biotite and sometimes with chlorite.

Occur.—Widely but rather sparsely distributed in schists, gneiss, slates, etc. A common product of fumarolic action, and frequent in pegmatites and pegmatitic veins. Apparently primary in some igneous rocks. Usually well rounded and flattened in sediments, as illustrated in Fig. 172.

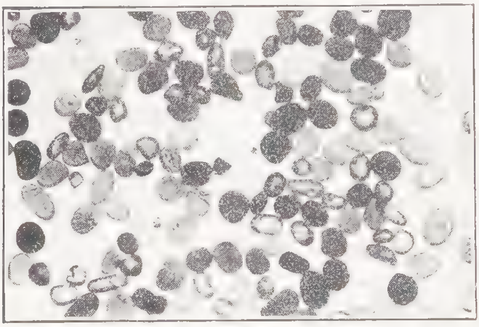


Fig. 172.—Tourmaline (the gray mineral) in heavy residues from sediments. Photomicrograph by Mrs. F. C. Edson.

Diag. — Readily distinguished by marked pleochroism with maximum absorption normal to the elongation; also by form, lack of cleavage, distinct relief and bright interference colors.

Cappelenite ($BaY_6B_6Si_3O_{25}$) is hexagonal with $c = 1.29$. Crystals thick prismatic without cleavage. H. = 6. G. = 4.4. F. = diff. Soluble in HCl. Uniaxial negative with $N_o = 1.76$ (est.), $N_o - N_e$ = rather strong. Color greenish brown. Found in veins in syenite. Very rare.

Melanocerite is a complex silicate of Ce, La, Y, Di, Ca, B, etc. Crystals trigonal with $c = 1.26$; tabular in habit without cleavage. H. = 5–6. G. = 4.13. F. = 7. Decomposed by HCl. Uniaxial negative with $N_o = 1.73 \pm$, $N_e = 1.72$, $N_o - N_e = 0.01 \pm$. Color brown to black; pale yellow in section. Alters to a reddish brown isotropic substance with $N = 1.77$. Found in veins in syenite. Very rare.

Caryocerite is a complex silicate of Ce, La, Di, Th, Ca, B, etc. Crystals trigonal with $c = 1.18$; tabular rhombohedral in habit without cleavage. H. = 5–6. G. = 4.29. F. = 7 with swelling. Decomposed by HCl. Isotropic (through alteration) with $N = 1.74 \pm$. Color brown. Found in a vein in syenite. Very rare.

Tritomite is a complex silicate of Ce, La, Di, Th, B, Ca, etc. Crystals trigonal with $c = 4.45$. Crystals acute pyramidal in habit with poor cleavage. H. = 5.5. G. = 4.2. F. = ?. Gelatinizes with HCl. Isotropic (through alteration) with $N = 1.75 \pm$ (1.73–1.76). Color dark brown. Found in syenite. Very rare.

DANBURITE Orthorhombic $a : b : c = 0.544 : 1 : 0.481$ $CaB_2Si_2O_8$

Phys. Char.—Crystals often prismatic with very poor 001 cleavage. H. = 7. G. = 3.0. F. = 3.5–4, giving green flame color. Nearly insoluble in HCl.

Opt. Prop.—The optic plane is 001 and X = *b*; on account of strong dispersion the mineral is negative for red, yellow and green light, but positive for blue light.

	Li	Na	Tl	CuSO$_4$
(−) 2V =	88°±	86° 54′ 89° 50′	89°±	(+) 2V = 89°±
N_g =	1.633 ±	1.636 ±	1.6393 ±	
N_m =	1.630-1.634	1.633 1.637	1.635-1.638	1.646
N_p =	1.626 ±	1.630 ±	1.6356 ±	
$N_g - N_p$ =	0.007	0.006	0.0037	

Color pale wine yellow, colorless, dark yellow, yellowish brown.

Occur.—In pegmatites and metamorphic rocks. Rare.

Diag.—Characterized by very large optic angle, strong dispersion and weak birefringence; differs from topaz in absence of good cleavage, smaller optic angle and lower density.

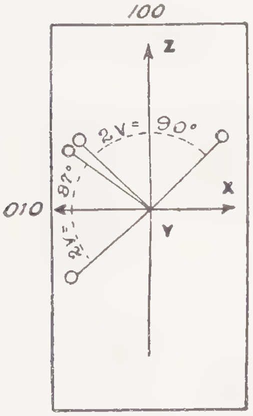


Fig. 173.—Optic orientation of danburite.

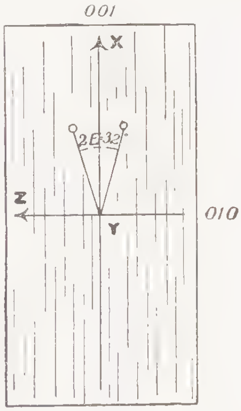


Fig. 174.—Optic orientation of kornerupite.

KORNERUPITE (*Kornerupine*) Orthorhombic $Mg_5(Al,B)_{12}Si_7O_{40}$?

$a : b : c = 0.862 : 1 : 0.435$

Comp.—The variety *prismatite* has one atom of Mg replaced by NaH. Boron was discovered in kornerupite by Gramont.[2]

Phys. Char.—Prismatic masses with distinct 110 cleavage. H. = 6.5. G. = 3.27–3.34. Prismatite is fusible; kornerupite, F. = 6. Insoluble in acids.

Opt. Prop.—The optic plane is 100; X = *c*. 2V = small with weak dispersion.

	Kornerupite		Prismatite	
(−) 2V =	20° Lacroix [2]		37° Ussing [3]	20° ± Uhlig [4]
N_g =	1.6742	1.6770	1.6818	1.6840
N_m =	1.6733	1.6766	1.6805	1.6826
N_p =	1.6613	1.6650	1.6691	1.6711
$N_g - N_p$ =	0.0129	0.010	0.0127	0.0129

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[2] A. Lacroix: *Comp. Rend.*, CLV, 1912, p. 674. *Minéral. Madagascar*, I, 1922, p. 396.

[3] *Zeit. Kryst.*, XV, 1889, p. 605.

[4] *Zeit. Kryst.*, XLVIII, 1910, p. 215.

There is evidently an isomorphous series with considerable variation of optic properties.

Kornerupite is white, yellow, brown, sea-green; prismatite is yellow to brown. In thin section the former is colorless, the latter yellowish; in thick plates kornerupite from Madagascar has X = reddish yellow, Y = clear yellow, Z = pale green; and prismatite has X = wine yellow, Y = brownish yellow, Z = greenish to colorless.

Alter.—Prismatite alters easily to a green fibrous mineral known as *kryptotile*, which is related to mica and chlorite; it contains no alkalies and may be a variety of leverrierite. It has H. = 2 3. G. = 3.05. F. = 6. Soluble in cold HF. Birefringent. Indices unknown.

Occur.—Kornerupite is found in schists with cordierite and sapphirite; also probably in pegmatite; prismatite occurs in "granulite" with albite, garnet and tourmaline. Both are very rare.

Diag.—Differ from sillimanite in negative elongation and weaker birefringence, from andalusite in higher refringence and smaller optic angle, and from topaz in prismatic cleavage, higher relief and negative elongation.

GRANDIDIERITE Orthorhombic $H_2Na_2(Mg,Fe)_7(Al,Fe,B)_{22}Si_7O_{56}$?

Comp.—Boron was discovered in grandidierite by Gramont.[2]

Phys. Char.—Crystal faces unknown; perfect 100 and distinct 010 cleavages. H. = 7.5. G. = 2.99. F. = 7. Insoluble in acids.

Opt. Prop.—The optic plane is 001; X = a; (−) 2V = 30°, $\rho < v$ very strong. N_g = 1.639, N_m = 1.636, N_p = 1.602, $N_g - N_p$ = 0.037. Color greenish blue with extreme pleochroism and X = dark bluish green, Y = colorless, Z = dark green and Z > X > Y.

Alter.—Alters readily to a green fibrous mineral similar to the alteration product (kryptotile) of prismatite.

Occur.—In pegmatite and aplite of Madagascar. Very rare.

Diag.—The pleochroism gives deep color across the elongtion and no color parallel thereto.

DUMORTIERITE Orth. $a : b : c = 0.890 : 1 : 0.687$ $HBAl_8Si_4O_{20}$

Phys. Char.—Crystals fibrous or columnar; twinning on 110 often as trillings. Distinct 100 and imperfect 110 cleavages; 001 parting. H. = 7. G. = 3.3. F. = 7. Insoluble even in HF.

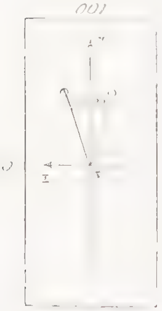

Fig. 175.—Optic orientation of dumortierite.

Opt. Prop.—The optic plane is 010; X = c. In twins the adjacent optic planes are at angles of about 60°. (−) 2V = 20° 40° (52° Walker[5]), $\rho < v$, strong to $\rho > v$, strong, N_g = 1.686, N_m = 1.684, N_p = 1.659, $N_g - N_p$ = 0.027 (Walker[5]); N_g = 1.689, N_m = 1.686, N_p = 1.678, $N_g - N_p$ = 0.011 (Linck); N_g = 1.690, N_m = 1.685, N_p = 1.677, $N_g - N_p$ = 0.013 (pink massive—Peck[6]); N_g = 1.692, N_m = 1.685, N_p = 1.675, $N_g - N_p$ = 0.017 (blue crystals—Peck[6]); N_g = 1.692, N_m = 1.691, N_p = 1.670, $N_g - N_p$ = 0.022 (Larsen). Color blue, greenish blue, reddish violet; strongly pleochroic in section with X = cobalt blue, violet, less commonly green, greenish brown, pink, Y = colorless, pale blue, pale violet, Z = colorless, pale blue.

The pleochroic colors parallel to X (= elongation) may be quite variable even in a single crystal, as blue, purple, red, brown, green, pink. Dumortierite inclusions in cordierite may cause pleochroic halos.

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[5] *U. Toronto Studies, Geol. Ser.*, 14, 1922, p. 80.

[6] *Am. Mineral.*, XI, 1926, p. 96.

ALTER.—Alters rather easily to a mica, probably sericite.

OCCUR —In pegmatite and gneiss. Very rare.

DIAG.—Intense pleochroism with maximum absorption parallel to elongation, and insolubility even in HF are characteristic.

Cerite $\{H_3(Ca,Fe)Ce_3Si_3O_{13}\}$ is orthorhombic with $a : b : c = 0.999 : 1 : 0.813$; crystals short prismatic, highly modified without cleavage. H. = 5.5. G. = 4.86–4.91. F. = 7. Gelatinizes with HCl. Optic orientation unknown. (+) 2V = 25°, $\rho < v$ very strong, $N_g = 1.821$, $N_m = 1.818$, $N_p = 1.817$, $N_g - N_p = 0.004$ (Larsen); 2V = very small, N = 1.81, $N_g - N_p = 0.002$ (Geijer [7]). Color brown, red, gray; pleochroic only in thick sections with X = nearly colorless, Y = ?, Z = pale reddish. Found in gneiss with allanite, etc. Very rare.

Hyalotekite ($Ca_3Ba_3Pb_3B_2Si_{12}O_{36}$?) is orthorhombic (?) with two cleavages at 90°. H. = 5–5.5. G. = 3.8. F. = 3(?). Insoluble in HCl. Optic plane parallel to intersection of the two cleavages. (+) 2V = small, $\rho < v$ strong. $N_g = 1.966$, $N_m = 1.963$, $N_p = 1.963$, $N_g - N_p = 0.003$. Colorless or gray. Found in ore deposits. Very rare.

Johnstrupite $\{Na_2O \cdot 3CaO \cdot Ce(F,OH)_3 \cdot (Ti,Zr)O_2 \cdot 5SiO_2?\}$ is monoclinic with $a : b : c = 1.623 : 1 : 1.391$, $\beta = 86° 56'$. Crystals long prismatic 100 plates, vertically striated. Distinct 100 cleavage. Lamellar twinning on 100. H. = 4. G. = 3.3. F. = 3. Soluble in HCl. Optic plane is 010; $X \wedge c = 2°$. (+) 2V = 70°, $\rho > v$ strong. $N_g = 1.673$, $N_m = 1.666$, $N_p = 1.661$, $N_g - N_p = 0.012$. Birefringence variable, as in epidote. Color brownish green; colorless in section. Found in Norway. Very rare.

Mosandrite is similar to johnstrupite; it has G. = 3.0. Optic plane is 010; $X \wedge c = 2°$. (+) 2V = 74°, $\rho > v$ strong. $N_g = 1.658$, $N_m = 1.649$, $N_p = 1.646$, $N_g - N_p = 0.012$. Birefringence variable as in epidote. Color reddish brown. Found in pegmatite in Norway. Very rare.

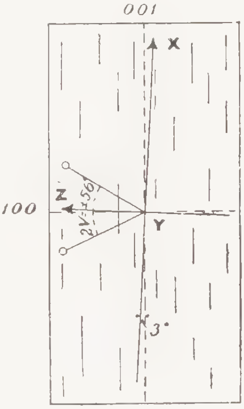

FIG. 176.—Optic orientation of mosandrite.

Rinkite $\{Na_2O \cdot 3CaO \cdot Ce(F,OH)_3 \cdot (Ti,Zr)O_2 \cdot 3SiO_2\}$ is monoclinic with $a : b : c$ [8] $= 1.601 : 1 : 0.657$, $\beta = 78° 34'$. Crystals prismatic or 100 tablets with distinct 100 cleavage. Lamellar twinning on 100. H. = 5. G. = 3.46. F. = 7. Attacked by H_2SO_4. Optic plane and X normal to 010; $Y \wedge c = -7.5°$ with distinct dispersion. (+) 2V = 43°, $\rho < v$ strong. $N_g = 1.681$, $N_m = 1.668$, $N_p = 1.665$, $N_g - N_p = 0.016$. Color yellow to brown; nearly colorless in section with X < Y < Z. Found in alkalisyenite in Greenland. Very rare.

Rinkolite [8a] is similar, but the optic plane is 010; $X \wedge c = 1.5°–3.5°$. (+)2V = 45°–88°, $\rho > v$, $N_g = 1.651–1.681$, $N_m = 1.645–1.667$, $N_p = 1.643–1.662$, $N_g - N_p = 0.008–0.019$. Color brown, green or yellow. *Lovchorrite* is a colloidal, partly isotropic variety. Very rare.

Searlesite [7] ($NaBSi_2O_6 \cdot H_2O$) is monoclinic with $a : b : c = 1.148 : 1 : 1.034$, $\beta = 76° 33'$. Perfect 100 cleavage. G. = 2.45. F. = easy. Soluble in HCl. Chemically related to analcite. Optic plane is normal to 010; $X \wedge c = 30° 15'$. (−) 2V = moderate(?), $N_g = 1.535$, $N_m = 1.533$, $N_p = 1.513$, $N_g - N_p = 0.022$, N_c on the cleavage = 1.529 (Rogers [9]). Also (−) 2V = very large, $N_g = 1.528$, $N_p = 1.520$, $N_g - N_p = 0.008$ (Larsen). Color white. Found in samples from the Searles deep well, Calif.

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[7] *Sver. Geol. Undcrs. Aarsbok*, 14, 1920, 6, p. 15.

[8] S. G. Gordon: *Proc. Phila. Acad. Sci.*, LXXVI, 1924, p. 267

[8a] A. E. Fersman: *Am. Mineral.*, XI, 1926, p. 289.

[9] A. F. Rogers: *Am. Jour. Sci.*, CCVII, 1924, p. 498.

Very rare. The optic properties change on treatment with acids; thus, after several hours in cold dilute HCl, $N_m = 1.465$, $N_g - N_p = 0.01$, and the elongation is positive with parallel extinction.

Chevkinite {*Tscheffkinite*—$(Ca,Fe)(Ce,Y,Di)_2(Si,Ti)_3O_{10}$} seems to be related to allanite.[10] It is monoclinic with $a : b : c = 2.426 : 1 : 1.955$, $\beta = 79° 52'$. No cleavage. H. = 5.5. G. = 4.3–4.55. F. = 4. Gelatinizes with HCl. (−) 2V = medium, $N_m = 1.88$, $N_g - N_p = 0.01$. Another crystal gave: (−) 2V = small, $N_m = 1.97$, $N_g - N_p = 0.02$. Again[10] (+) 2V = 80° to (−) 2V = 78°, N = 1.63–1.68, $N_g - N_p = 0.0035$. Color velvet black with X = nearly colorless, Y = pale red-brown, Z = dark red-brown. Also in part apparently amorphous and isotropic with N = 1.88, and in another case N = 1.965. Color red-brown. Rare.

DATOLITE MONOCLINIC $HCaBSiO_5$

$a : b : c = 0.633 : 1 : 0.635 \quad \beta = 89° \; 51'$

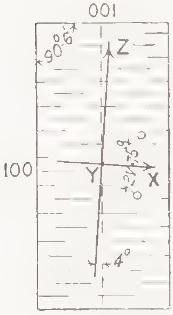

FIG. 177.—Optic orientation of datolite.

PHYS. CHAR.—Crystals short prismatic, with 001 or highly modified pyramidal forms, without distinct cleavage. H. = 5–5.5. G. = 2.9–3.0. F. = 2–2.5. Gelatinizes with HCl.

OPT. PROP.—The optic plane is 010; $Z \wedge c = -1°$ to $-4°$ with dispersion. (−) 2V = 74°, $\rho > v$ weak, $N_g = 1.670$ Na, $N_m = 1.653$, $N_p = 1.625$, $N_g - N_p = 0.045$. Color white or tinted; colorless in section.

OCCUR.—Always secondary; often associated with zeolites and calcite in amygdules; also in veins, etc.

DIAG.—Usually in crystals of characteristic forms; contains boron without aluminum.

HOMILITE MONO. $a : b : c = 0.625 : 1 : 0.642$ $\beta = 89° \; 38'$ $Ca_2FeB_2Si_2O_{10}$

PHYS. CHAR.—Crystals 001 tablets or pseudopyramidal with 110 and 012 or $\bar{1}11$. Twinning on 001; cleavage indistinct. H. = 5. G. = 3.36. F. = 2 to a black glass. Gelatinizes with HCl.

OPT. PROP.—Optic plane and Z normal to 010; $Y \wedge c = -1°$. (+) 2V = 80°, $\rho > v$, distinct, with very strong horizontal dispersion. $N_g = 1.738$, $N_m = 1.725$, $N_p = 1.715$, $N_g - N_p = 0.023$. Color black to dark brown. No distinct pleochroism in thin section; in thick section, X = bluish green, Y = deep brownish red to brownish gray, Z = smoky gray or brownish yellow, and Y > X > Z.

ALTER.—Alters easily to isotropic condition with N = 1.640; an altered border may have variable properties, as follows: (+) 2E = 0°–78°,

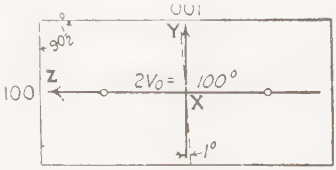

FIG. 178.—Optic orientation of homilite.

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[10] A. Boldireff: *Bull. Soc. Fr. Min.*, XLVIII, 1925, p. 120; *N. Jahrb. Min.*, I, 1926, p. 247.

2V = 0°–45°, $\rho > v$ very strong or $\rho < v$ very strong, $N_m = 1.665–1.630$, $N_g - N_p = 0.02$. Color yellow.

Occur.—In pegmatite. Rare.

Diag.—Characterized by high relief, amorphous alteration product, no cleavage, greenish color and lack of pleochroism in this section.

GADOLINITE Mono. $a : b : c = 0.627 : 1 : 0.661$ $\beta = 89° 27'$ $Be_2FeY_2Si_2O_{10}$

Comp.—May contain much cerium,[11] e.g., 23.4 per cent Ce_2O_3.

Phys. Char.—Crystals rough prismatic, without cleavage. H. = 6.5–7. G. = 4.0–4.6, decreasing with alteration. Gelatinizes with HCl.

Opt. Prop.—The optic plane is 010; $Z \wedge c = +6°$ to $+10°$ (in green type) and $+12°$ to $14°$ (in brown type). (+) 2V = 85°±, $\rho < v$, strong (green type). $N_g = 1.777–1.785$ (Larsen); $N_m = 1.78 \pm$, $N_p = 1.772–1.780$, $N_g - N_p = 0.010 \pm$ (variable, strong to zero through alteration). $N_g = 1.824$ (Vogt[11]), $N_m = 1.812$, $N_p = 1.801$, $N_g - N_p = 0.023$. Color black, greenish, brown; in thin section green or brown without perceptible pleochroism; in thick section X = olive green, Y = Z = grass green.

Alter.—Easily alters to an isotropic state with $N = 1.78 \pm$.

Occur.—Chiefly in pegmatite often with fluorite. Rare.

Diag.—Variable birefringence, high relief, lack of pleochroism and cleavage, large optic angle and presence of rare earths.

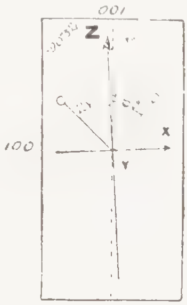

Fig. 179.—Optic orientation of gadolinite.

Hellandite $\{Ca(Al,Y,Er,Fe \cdot OH)_3Si_2O_8\}$ is monoclinic with $a : b : c = 2.065 : 1 : 2.151$, $\beta = 70° 15'$. Crystals 010 tablets, etc. Twinning on 001, also in bands on 100. H. = 5.5. G. = 3.35–3.70. F. = easy. Soluble in HCl. Optic plane normal to 010; $Z \wedge c = -43.5°$, (+) 2V = 80°±, $N_m = 1.65$ (est.), $N_g - N_p = 0.01 \pm$, decreasing with alteration. Color brown to red. During gradual alteration, the birefringence and extinction angle ($Z \wedge c$) both decrease toward zero. Found in pegmatite with tourmaline, thorite, allanite, etc. Very rare.

Serendibite $\{(Fe,Ca,Mg)_5Al_5BSi_3O_{20}\}$ is probably triclinic with lamellar twinning like plagioclase. No cleavage. H. = 6.5–7. G. = 3.42. F. = 7. Nearly insoluble in acid. Sections normal to twinning and nearly normal to Z have extinction at 35° to 40°. (+) 2V = nearly 90°, $\rho < v$, strong; $N_g = 1.706$, $N_m = 1.703$, $N_p = 1.701$, $N_g - N_p = 0.005$. Color sky to indigo blue with (X and) Y = yellow or green, Z = blue. Found in contact zones in Ceylon. Very rare.

AXINITE Triclinic $H(Fe,Mn)Ca_2Al_2BSi_4O_{16}$

$a : b : c$[12] $= 0.602 : 1 : 0.827$ $\alpha = 121° 32'$ $\beta = 44° 42'$ $\gamma = 140° 20'$

Phys. Char.—Crystals usually wedge-shaped (whence the name) with good $\bar{1}12$, 010, and $1\bar{3}0$ and poor 001 cleavages. H = 6.5–7. G. = 3.25–3.30. F. = 2 with intumescence. Insoluble in acid.

Opt. Prop.—The negative acute bisectrix X is nearly normal to 011. The optic angle is somewhat variable even in a single crystal.

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[11] *Vid. Skr. I. Mat. nat. Kl.*, 1922, No. 1, pp. 26 and 44. Data on very fresh material.

[12] There is no agreement as to the fundamental form of axinite; the parameters given above are those of Des Cloizeaux.

The optic properties vary somewhat with variations in composition, as follows:

	Manganaxinite[13]		Feraxinite	
(−) $2V =$	$70°–76°$ Na, $\rho < v$		$71°–75°$ $\rho < v$	
$N_g =$	1.689 Na		1.681 red	1.695 blue
$N_m =$	1.685 Na		1.678 red	1.692 blue
$N_p =$	1.679 Na		1.672 red	1.685 blue
$N_g - N_p =$	0.010 Na		0.009 red	0.010 blue
$Z' \wedge$ 001 in 011 $=$	$3°–8°$ red	$2°–6°$ violet	$24° 40'$	
$Z' \wedge$ $1\bar{1}0$ in 011 $=$	$55°–63°$		$40°$	
$X \wedge \perp$ 011 $=$	$1°–7°$		$0° \pm$	

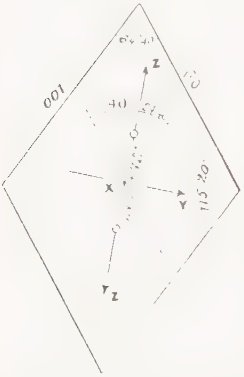

FIG. 180.—Optic orientation of axinite in a section parallel to 011.

In blue axinite the optic angle attains 83° and in rare cases it reaches 90°. In manganaxinite there is distinct crossed dispersion, while in feraxinite the axial dispersion is scarcely perceptible in oil, but marked in air, while the horizontal and inclined dispersion is distinct and crossed dispersion is nearly zero.

Color brown, gray, dull blue; manganaxinite is yellow to greenish yellow; pleochroism very distinct in thick sections but may be lacking in thin section. Illustrations of pleochroic colors follow.

	Sections .02 mm. thick	Sections 3 mm. thick
X =	colorless, pale yellow	cinnamon brown, clear yellow
Y =	pale violet, clear yellow, sky blue	deep violet, sulphur yellow, deep blue
Z =	colorless, pale greenish	olive yellow, colorless

The axes of maximum, median and minimum absorption do not coincide with Z, Y, Z; if they are, respectively, D, E, F, then[14]:

$$\begin{array}{lll}
D \wedge X = 79° \; 2' & E \wedge X = 11° \; 24' & F \wedge X = 86° \; 41' \\
D \wedge Y = 10° \; 58' & E \wedge Y = 100° \; 57' & F \wedge Y = 90° \; 36' \\
D \wedge Z = 90° \; 0' & E \wedge Z = 93° \; 8' & F \wedge Z = 3° \; 8'
\end{array}$$

OCCUR.—Usually a product of fumarolic action in contacts; also in veins.

DIAG.—The form is characteristic; the relief is much higher than that of orthoclase; the pleochroic colors are notable in thick sections.

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[13] V. M. Goldschmidt: *Vid. Skr. Kristiania*, 1911, I, p. 448.

[14] Lang: *Sitzb. Akad. Wiss. Wien. Math. Kl.*, CXIX, 1910, p. 949.

10. ANHYDROUS SILICATES OF Al (Cr, Fe, Mn) AND ONE OR MORE OTHER BASES (INCLUDING FELDSPARS AND FELDSPATHOIDS)

LEUCITE GROUP

The minerals here assigned to the leucite group are:

Leucite	Pseudoisometric	$KAlSi_2O_6$
Pollucite	Isometric	$4CsAlSi_2O_6 \cdot H_2SiO_3$
Analcite	Pseudoisometric	$NaAlSi_2O_6 \cdot H_2O$

Pollucite is not anhydrous, but is included here, nevertheless, because it is chemically and crystallographically similar to leucite. In the same way, as urged by Wherry,[1] it is reasonable to add analcite to this group; it contains too little water for a typical zeolite and does not intumesce on heating.

LEUCITE PSEUDOISOMETRIC $KAlSi_2O_6$

PHYS. CHAR.—Crystals usually trapezohedral, often with 100 or 110, with very indistinct 110 cleavage. H. = 5.5–6. G. = 2.47. F. = 7. Decomposed by HCl.

OPT. PROP.—Small crystals usually isotropic; large crystals usually weakly anisotropic, the isometric symmetry being metastable or unstable below about 600° C., the external isometric form is maintained by means of complicated twinning on 110 of an orthorhombic(?) unit. (+) 2V = very small, $N_g = 1.509$, $N_p = 1.508$, $N_g - N_p =$

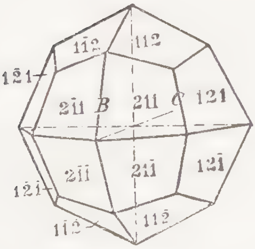

FIG. 181.—A crystal form of leucite.

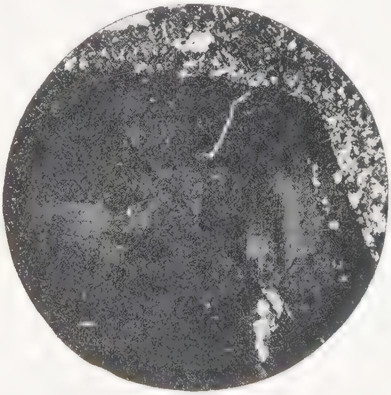

FIG. 182.—Photomicrograph of leucite in thin section showing weak birefringence.

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[1] *Am. Mineral.*, VIII, 1923, p. 1.

0.001 (N = 1.5054 B, 1.5146 F). The weakly birefringent twinning bands are seen more easily by superposing a sensitive tint plate.

Colorless, white, gray. Colorless in thin section.

INVER.—The inversion temperature to the isometric form is variously reported at 500° to 700° C. A recent study [2] suggests the existence of a temperature-inversion interval of about 30°.

INCL.—Inclusions of glass, magnetite, etc., common; they may be regularly arranged either radially or parallel to the faces of the leucite. Various stages in the development of radial inclusions through growth of skeleton crystals are shown in Fig. 183.

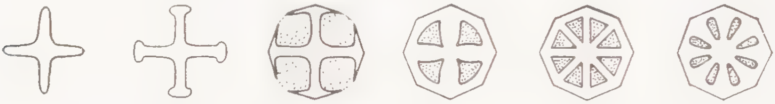

FIG. 183.—Radial inclusions in leucite resulting from development of skeletal forms. (After Pirsson.)

ALTER.—Leucite alters easily, either to analcite (in Tertiary and recent lavas) or to the so-called pseudoleucite (in Paleozoic rocks), which is a mixture of albite and sericite, orthoclase and sericite, or orthoclase and nephelite.

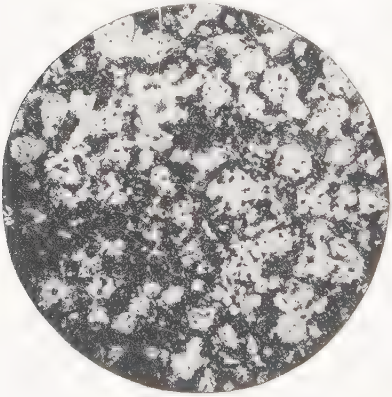

FIG. 184.—Photomicrograph of leucite crystals in thin section showing imperfect radial inclusions.

OCCUR.—Only in igneous rocks low in silica and high in potassa. Either in groundmass or as phenocrysts. Chiefly confined to Tertiary and recent lavas, because almost completely altered in older rocks.

DIAG.—The low refringence, crystal form, complex lamellar twinning, and very weak birefringence distinguish leucite from all minerals except analcite; it differs from analcite (and sodalite) by higher refringence and presence of potassium; if heated to redness, analcite loses water and becomes opaque, while leucite remains unaltered.

Pollucite ($4CsAlSi_2O_6 \cdot H_2SiO_3$) is isometric often in cubes. Cleavage only in traces. H. = 6.5. G. = 2.9. F. = 6. Isotropic with N = 1.5215 Li, 1.5247 Na, 1.5273 Tl. Colorless. Found in cavities in granite. Rare.

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[2] F. Rinne and R. Kolb: *N. Jahrb. Mineral.*, 1910, II, p. 154.

ANALCITE PSEUDOISOMETRIC $NaAlSi_2O_6 \cdot H_2O$

COMP.—Both H_2O and SiO_2 sometimes present in excess of amount indicated by formula.

PHYS. CHAR.—Trapezohedral crystals not rare; also more complex forms or compact. Complex penetration twinning common. Very difficult 001 cleavage. H. = 5–5.5. G. = 2.22–2.29. F. = 2.5 to colorless glass. Gelatinizes with HCl.

OPT. PROP.—Usually isotropic with N = 1.489–1.479; large crystals often very weakly anisotropic with complicated twinning and (−) 2V = small to large. N = 1.487 ±, $N_g - N_p = 0.001$.

Colorless, white, grayish, greenish, etc. Colorless in thin section.

OCCUR.—Usually a secondary mineral, often associated with zeolites, and may be an alteration product of nephelite or sodalite. Also a primary constituent of igneous rocks, at times taken for leucite.

DIAG.—Distinguished by very low refringence, and nearly or quite isotropic character. It differs from sodalite by the absence of color, often present in the latter, and different cleavage; it differs from leucite in the absence of regularly arranged inclusions common in the latter, lower refringence and presence of soda and water; it has higher refringence than opal and distinctly lower index than rock glass. Chemical tests may be needed to identify it with certainty.

GARNET GROUP

CLASS.—If a mineral species is a natural substance which varies between definite natural limits in chemical composition then there are probably two and only two species in the garnet group, since three of the types commonly recognized belong to one continuous series and the other three to another. Neither species has received a name, but designations may be coined from the abbreviations of the names of the chemical types, as follows:

Pyralspite	Pyrope	$Mg_3Al_2Si_3O_{12}$
	Almandite	$Fe_3Al_2Si_3O_{12}$
	Spessartite	$Mn_3Al_2Si_3O_{12}$
Ugrandite	Uvarovite	$Ca_3Cr_2Si_3O_{12}$
	Grossularite	$Ca_3Al_2Si_3O_{12}$
	Andradite	$Ca_3Fe_2Si_3O_{12}$

There are still other types; for example, in *schorlomite* Ti replaces part of the Si (and also Fe?) of andradite; in India garnets are known containing as much as 10 per cent Mn_2O_3, etc. It is well known that garnets do not usually correspond to any single chemical type, but contain two or more molecules in mutual crystal solution. Ford[3] found that one-sixth of all analyzed garnets contained only two molecules (each at least 5 per cent); another sixth contained four molecules

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[3] *Am. Jour. Sci.*, CXC, 1915, p. 33.

(each at least 5 per cent) and the remaining two-thirds consisted of three molecules. In garnets containing three (or four) molecules two (or even one) are always predominant and the third (also the fourth) averages about 5 per cent and is not known to exceed 20 per cent. The approximate mutual solubilities of the two chief types and the continuity of the grossularite-andradite series are shown in Fig. 185, as determined by Boeke[4] from a study of all analyses. These limits are subject to correction, but it is not likely that the wide gap between pyralspite and ugrandite will ever be eliminated,

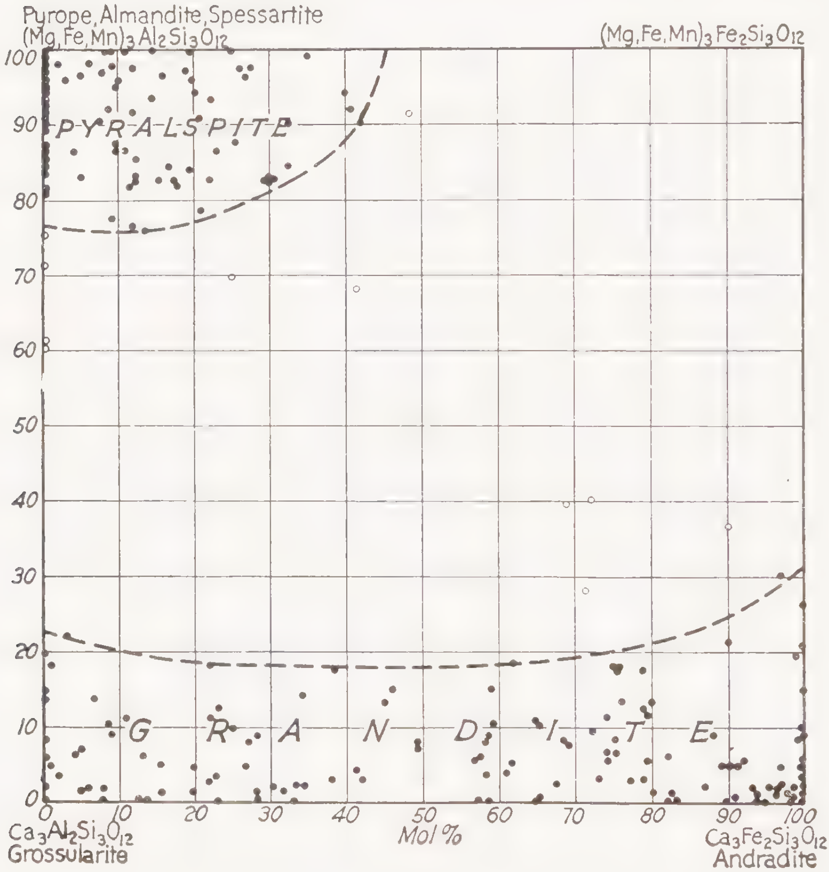

FIG. 185.—Variations in composition in garnet. Modified from Boeke: *Zeit. Kryst.*, LIII, 1914, p. 149.

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[4] *Zeit. Kryst.*, LIII, 1914, p. 149.

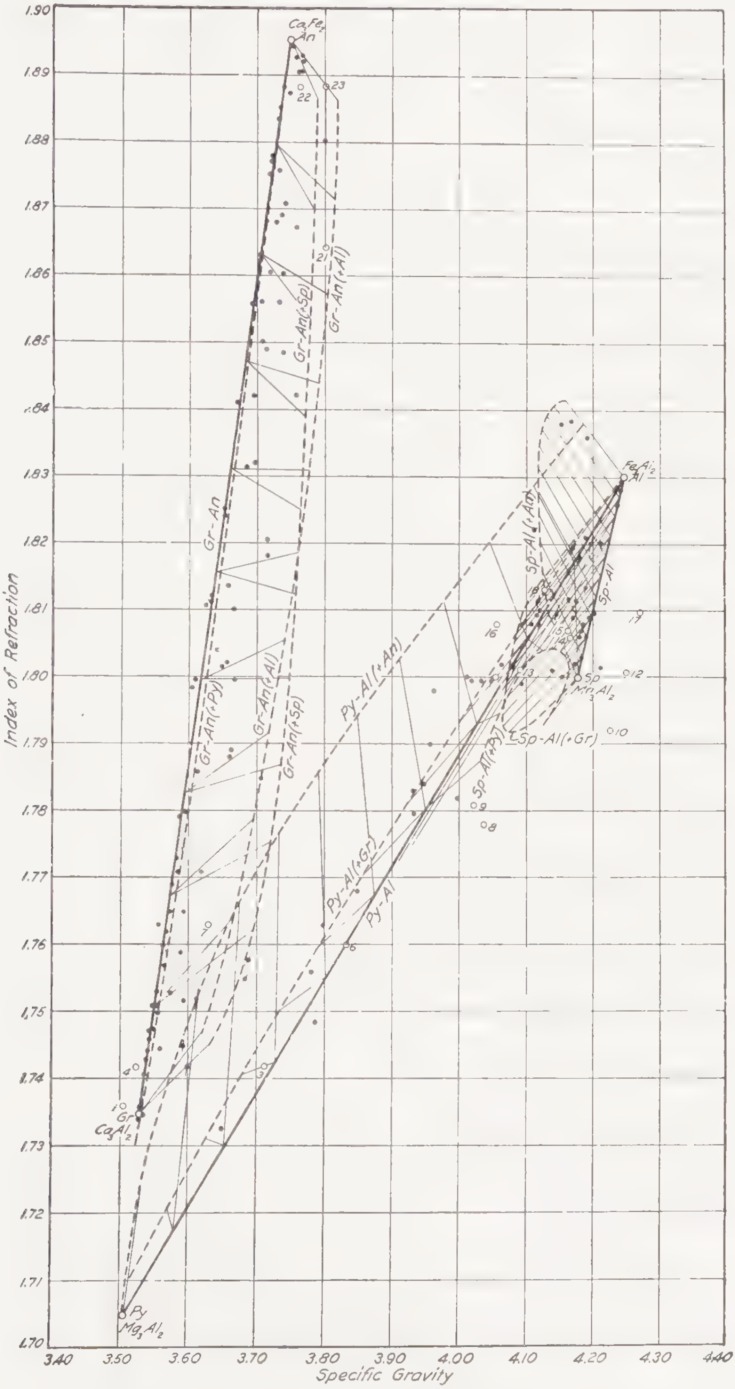

FIG. 186.—Variations in refringence and specific gravity in garnet.

though Fermor[5] has described a type supposed to be intermediate between spessartite and andradite.

The differences in specific gravity and refringence between the two kinds of garnet are shown in Fig. 186; furthermore, pyralspite is practically always isotropic, while ugrandite is commonly anisotropic.

Phys. Char.—Crystals very common, usually dodecahedrons; also trapezohedrons or dodecahedrons with trapezohedral faces, or either with hexoctahedral faces; octahedrons very rare. Microscopic twinning rare. No cleavage. H. = 6.5–7.5. G. = 3.4–4.3. F. = 3–7. Nearly or quite insoluble in acids including HF, except schorlomite.

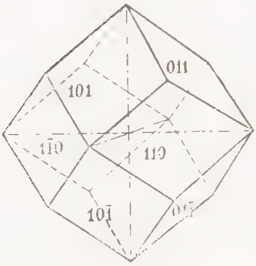

Fig. 187.—A crystal form of garnet.

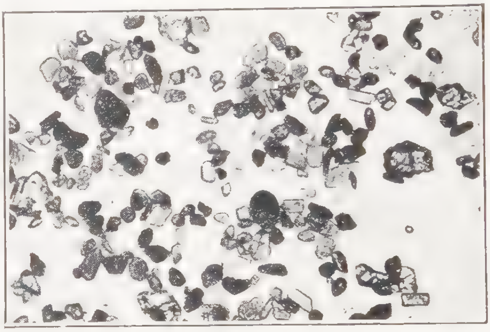

Fig. 188.—Garnet in heavy residues from sediments. Photomicrograph by Mrs. F. C. Edson.

Opt. Prop.—Commonly isotropic, especially small crystals in thin sections, with N = 1.70 to 1.90 (in schorlomite, 2. ±), giving marked relief in thin section. Color variable, often bright, being red, brown, yellow, white, green, black.

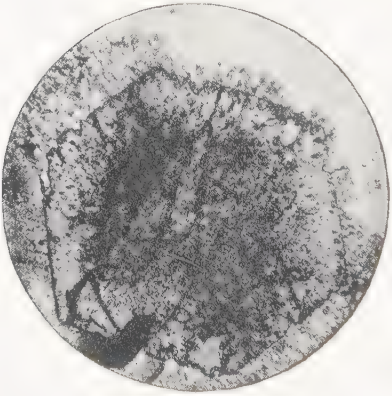

Fig. 189.—Photomicrograph of a large garnet crystal in thin section.

Occur.—Common in mica schist, hornblende and chlorite schists and gneisses. Found also in many plutonic rocks; more rarely in volcanic rocks. Common in contact altered limestones. Very abundant in certain rocks, such as garnet schists and eclogites. Not rare in some sediments.

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[5] *Geol. Surv. India, Mem.*, XXXVII, 1909, p. 179.

DIAG.—The dodecahedral form is a useful diagnostic. In thin section garnet shows no cleavage, and very high relief, with a shagreen surface. Usually isotropic and often pink in color. Some of the distinctions between various types may be tabulated as follows:

Name	G	Pyrognostic Characters	N	Colors	After fusion	
					G	N
Pyrope	3.51	F=4 to black non-mag. globule	1.705	Red to nearly black	3.0±	
Almandite	4.25	F.=3 to dark magnetic globule	1.830	Brown, red, black	3.4±	
Spessartite	4.18	F.=3 to black non-mag. globule Reacts for manganese	1.800	Shades of red		
Uvarovite	3.7?	F.=7 Reacts for chromium	1.870	Emerald green		
Grossularite	3.53	F.=3 to pale non-mag. globule	1.735	Yellow, white, brown, red, green	2.9±	1.62±
Andradite	3.75	F.=3 to black magnetic globule	1.895	Yellow, brown, red, black	3.2±	1.8±

PYRALSPITE

PYROPE $Mg_3Al_2Si_3O_{12}$
ALMANDITE ISOMETRIC $Fe_3Al_2Si_3O_{12}$
SPESSARTITE $Mn_3Al_2Si_3O_{12}$

COMP.—Pyralspite may contain up to about 25 per cent of grossularite or of andradite in crystal solution, as shown in Fig. 185.

PHYS. CHAR.—Crystal form not common in *pyrope* ($Mg_3Al_2Si_3O_{12}$); usually the dodecahedron or trapezohedron in *almandite* ($Fe_3Al_2Si_3O_{12}$) and *spessartite* ($Mn_3Al_2Si_3O_{12}$). Cubic faces known in pyrope. Faces may be striated in almandite in which indistinct 110 parting is known. H. = 7–7.5. G. = 3.5–3.8 (pyrope), 4.1–4.3 (almandite), 3.8–4.25 (spessartite). F. = 3–4 to dark globule, magnetic if Fe is present. Insoluble in acids, even HF.

OPT. PROP.—Always isotropic, except spessartite which may be indistinctly anisotropic. N = 1.70–1.83, varying with the composition as shown in Figs. 190 and 191. In pyrope N = 1.705; in almandite N = 1.830; in spessartite N = 1.800. *Rhodolite* with FeO = 15.6, MgO = 17.2 and Fe_2O_3 = 1.9 has N = 1.760. Garnet[6] with FeO = 27.8, MnO = 14.3 and MgO = 1.0 has N = 1.818.

Color of pyrope red of various shades, rarely black; in thin section red to yellowish brown. Color of almandite red, brownish, violet, black; in thin section brown to reddish. Color of spessartite red of various shades or yellowish brown; in thin section pale pink.

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[6] E. V. Shannon: *Am. Mineral.*, VII, 1922, p. 171.

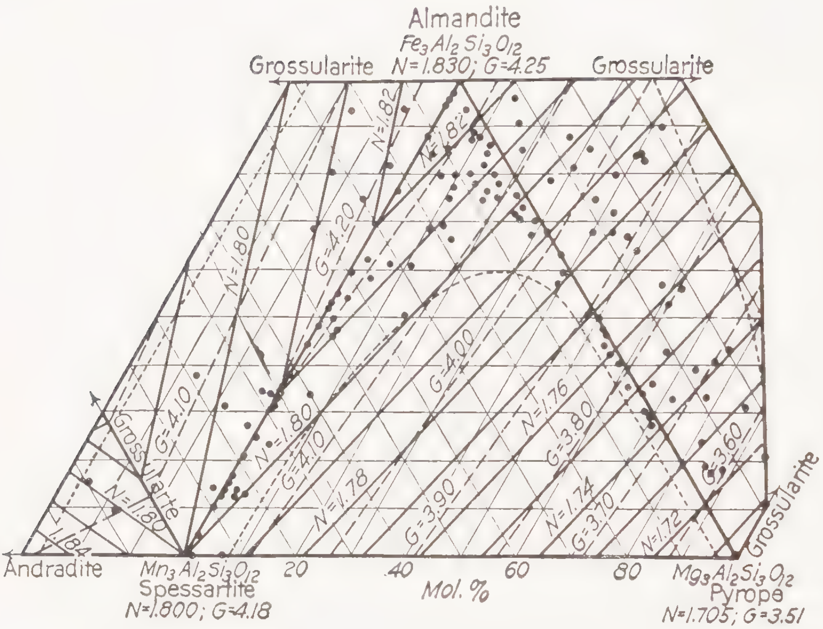

FIG. 190.—Variations of composition and optic properties in pyralspite (+ grossularite) Dotted lines indicate estimated limits of crystal solubility. Based on data of Ford (*Am. Jour. Sci.*, CXC, 1915, p. 33), Boeke (*Zeit. Kryst.*, LIII, 1914, p. 149) and others.

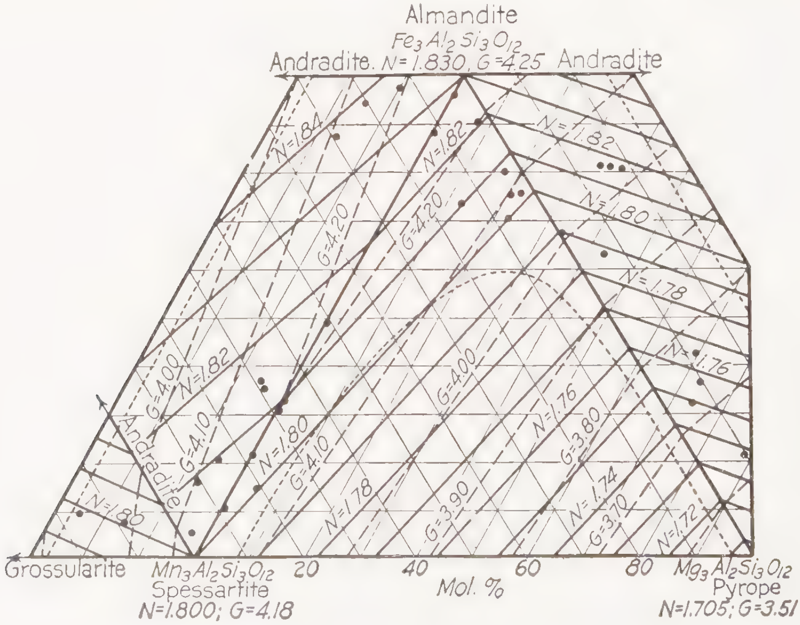

FIG. 191.—Variations of composition and optic properties in pyralspite (+ andradite). Dotted lines indicate estimated limits of crystal solubility. Based on data of Ford, Boeke, and others.

ALTER.—Pyrope alters to a green substance called *kelyphite* which forms a crust about the garnet grains consisting usually of an intergrowth of fibrous amphibole and feldspar. Pyrope also alters to chlorite. Almandite alters readily to chlorite and epidote; less commonly to biotite, hornblende, scapolite, feldspar, hematite, etc. When fused and recrystallized in nature it forms a green spinel and hypersthene. Spessartite is known to alter to biotite.

OCCUR.—Pyrope is found especially in peridotites and derived serpentines; it is found in the "blue ground" of the diamond mines of South Africa. Almandite is common in schists, gneisses and some granulites; it is an essential constituent of eclogite and found in some amphibolites. It is rare in granite and in contact rocks. Spessartite is found in mica schist, pegmatite, quartzite, and in lithophysæ in rhyolite.

DIAG.—See the table on page 261. Pyralspite differs from ugrandite in the almost complete absence of birefringence; this fact together with a determination of the refractive index and the use of Figs. 186, 190, and 191 will give the approximate composition of the garnet. Further, pyrope seems to be confined to peridotites and serpentine.

UGRANDITE	**UVAROVITE**	$Ca_3Cr_2Si_3O_{12}$
	GROSSULARITE	$Ca_3Al_2Si_3O_{12}$
	ANDRADITE	$Ca_3Fe_2Si_3O_{12}$

ISOMETRIC (above 800° C.)

COMP.—Ugrandite may contain up to about 20 per cent of almandite, spessartite or pyrope in crystal solution as shown in Fig. 185.

PHYS. CHAR.—Crystals usually dodecahedral; the trapezohedron is not rare; hexoctahedral faces modify these; the octahedron is very rare. Striations may occur on the dodecahedral faces. No cleavage. H. = 6.5–7. G. = 3.4–3.8 (uvarovite), 3.4–3.6 (grossularite), 3.7–4.1 (andradite). F. = 7 (uvarovite), 3 to pale non-magnetic globule (grossularite), 3.5 to black magnetic globule (andradite). Nearly or quite insoluble in acids including HF. But *schorlomite* (the titaniferous andradite) gelatinizes with HCl.

OPT. PROP.—Small crystals may be isotropic, but ugrandite usually shows birefringence, especially in thick sections. The isometric external form is then retained by twinning, the twinned units being pyramids whose vertices meet at the center and whose bases are the external faces of the isometric form. Some garnets may be separated mechanically into parts corresponding to these pyramids.

The various types of twinning correspond with the external forms, as follows:

1. *Dodecahedral type* (the commonest). The crystal is composed of twelve rhombic pyramids in each of which the optic plane is parallel to the long diagonal of the rhombic face and the obtuse bisectrix X is normal to the face. The optic angle (2V) is about 50°–90° and the dispersion is strong with $\rho < v$. The birefringence may attain 0.003.

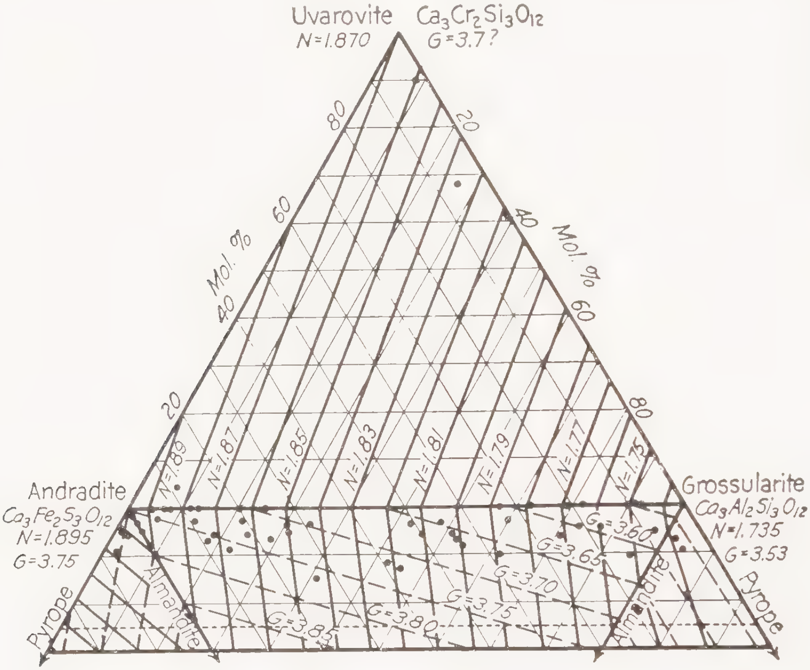

FIG. 192.—Variations of composition and optic properties in ugrandite (+ almandite). Based on data of Ford, Boeke and others.

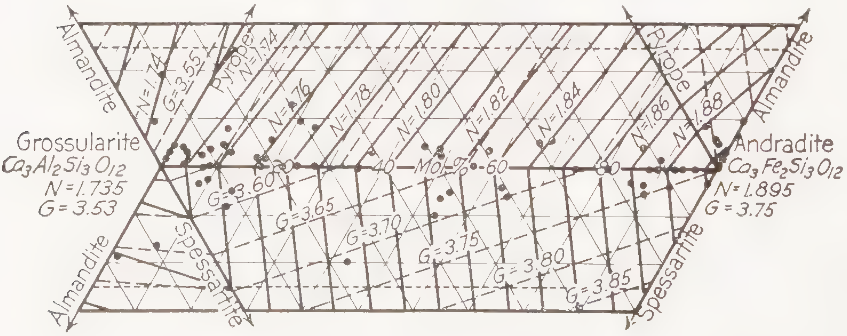

FIG. 193.—Variations of composition and optic properties in grandite (+ pyrope and spessartite). Based on data of Ford, Boeke and others.

2. *Hexoctahedral type* The external form is a dodecahedron modified by the hexoc-

tahedron; it is built up of forty-eight unsymmetrical triangular pyramids; in each the optic plane makes an angle of 2°–17° with the long diagonal of the dodecahedral face, while the negative acute bisectrix X is somewhat inclined to the normal to the same face.

3. *Trapezohedral type.* The crystal is a trapezohedron composed of twenty-four pyramids in each of which the optic plane is normal to the symmetrical diagonal of the trapezohedral face to which the positive acute bisectrix is also perpendicular.

4. *Octahedral type.* Rare octahedral garnets from Elba are composed of eight triangular pyramids each of which is uniaxial, the negative optic axis being normal to the octahedral face.

5. In some garnets more than one of these types may be present in a single crystal. Also, the crystal may be made up of zones or layers which may be separated mechanically; one zone may show one type of twinning and the next zone a different one. In some crystals different types interpenetrate. Finally, crystals are often composed of parts which are anisotropic together with others which are isotropic.

Refringence of ugrandite high, with N = 1.73–1.90; in uvarovite N = 1.870, in grossularite N = 1.735, in andradite N = 1.895. The index varies with variations in composition as shown in Figs. 192 and 193.

Color of uvarovite emerald green, in thin section green. Color of grossularite yellow, brown, gray, greenish, white, red, and colorless to yellowish brown in thin section. Color of andradite black to red, brown, greenish yellow; often dark colored even in thin section. Not pleochroic.

INVER.—The birefringent type inverts[7] at about 800° C. to a strictly isotropic form. Ugrandite of igneous rocks does not always invert on cooling to the birefringent condition.

ALTER.—Uvarovite may alter to a dark-green chlorite, doubtless containing chromium. Grossularite is known to alter to epidote, chlorite, feldspar and calcite. Andradite may change to epidote, limonite, feldspar and calcite.

OCCUR.—Uvarovite is rare, but is known in gneiss, serpentine, and in cavities in chromite, as well as in contact altered limestones. Grossularite is common in limestone contacts and also found in schists, in veins, and in nephelite syenite. Andradite is not rare in limestone contacts and is found also in schists, serpentine, nephelite syenite and some acid igneous rocks.

DIAG.—See the table on page 261. Ugrandite usually shows birefringence which is rare in pyralspite; this difference together with a measurement of the index and the use of Figs. 186, 192 and 193 will give the approximate composition of the garnet. Further, ugrandite is common in limestone contacts, where pyralspite is uncommon.

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[7] H. E. Merwin: *U. S. Geol. Surv. P. P.* 87, 1915, p. 108.

Schorlomite is a titaniferous ugrandite (usually a variety of andradite); the titanium seems to replace (in part) not only SiO_2, but also Fe_2O_3. Increase of TiO_2 causes increase of refringence, but the relation is not simple since other elements also vary. Schorlomite is grayish black, hence the name for black garnet (*melanite*) is sometimes applied to it. The following data [8] illustrate variations in index.

Melanite, New Haven, Conn.	$TiO_2 = 0.0$	$N = 1.86–1.88$
Schorlomite (" Andradite "), Colo. [9]	$TiO_2 = 5.08$	$N = 1.907$
Schorlomite (" Melanite "), Colo.	$TiO_2 = 5.1$	$N = 1.95$
Schorlomite (" Melanite "), Italy [10]	$TiO_2 = 8.7$	$N = 1.94$
Schorlomite, Magnet Cove, Ark.	$TiO_2 = 16.9$	$N = 1.94$
Schorlomite, Magnet Cove, Ark.	$TiO_2 = ?$	$N = 1.98$
Schorlomite (" *Ivaarite* "), Finland	$TiO_2 = 19.0$	$N = 2.01$

Plazolite [11] $\{3CaO \cdot Al_2O_3 \cdot 2(SiO_2,CO_2) \cdot 2H_2O\}$ is isometric and closely related to ugrandite garnet. Crystals dodecahedral without cleavage. H. = 6.5. G. = 3.13. Isotropic with N = 1.710. Colorless. Found in contact-altered limestone. Rare.

MELILITE GROUP

The minerals of the melilite group are tetragonal silicates of calcium (or, in part, sodium) usually with magnesium or aluminum, less commonly with iron, manganese or zinc.

Phys. Char.—The crystals are usually short square prisms with or without pyramidal faces, with indistinct 100 and 001 cleavages. Cruciform twinning rare. H. = 5–6. G. = 2.9–3.4. F. = 3–6. Gelatinizes with HCl.

Opt. Prop.—Uniaxial with moderate to high relief and very weak to moderate birefringence; all types are negative except akermanite; certain proportions of akermanite lead to crystals which are isotropic for certain colors; crystals isotropic, or nearly so, commonly show abnormal interference colors.

Occur.—In very basic igneous rocks and in slags.

Diag.—Distinct relief, weak birefringence, uniaxial character, common abnormal interference colors and mode of occurrence are distinctive.

Class.—The type formula [12] of melilite is R_5O_7, in which R stands for one, two (or three?) atoms of Si and all the bases. The members of the group include:

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[8] H. S. Washington and H. E. Merwin: *Am. Jour. Sci.*, CC, 1920, p. 33.

[9] E. S. Larsen and J. F. Hunter: *Jour. Wash. Acad. Sci.*, IV, 1914, p. 478.

[10] Further $SiO_2 = 29.7$, $Al_2O_3 = 8.1$, $Fe_2O_3 = 23.6$, $MgO = 0.7$, $CaO = 28.8$.

[11] W. F. Foshag: *Am. Mineral.*, V, 1920, p. 183.

[12] A. N. Winchell: *Am. Jour. Sci.*, CCVIII, 1924, p. 375.

Hardystonite		$Ca_2ZnSi_2O_7$	Impure mineral
....		$Ca_2MnSi_2O_7$	In slag (mix-crystal)
Akermanite	$c = 0.45 \pm$	$Ca_2MgSi_2O_7$	Pure (artificial)
Calcium-akermanite		$Ca_3Si_2O_7$	Hypothetical (in mix-crystals)
Iron-akermanite		$Ca_2Fe''Si_2O_7$	In slags
Gehlenite	$c = 0.40 \pm$	$Ca_2Al_2SiO_7$	Pure (artificial)
Iron-gehlenite		$Ca_2Fe'''_2SiO_7$	Hypothetical (in mix-crystals)
Sodium-melilite		$Na_2Si_3O_7$?	Hypothetical (in mix-crystals)

The composition of the sodium melilite molecule is commonly given as $(Na_2)_3Al_2Si_3O_{12}$, which is very improbable because it is entirely different in type from the melilite formula; the correct formula is unknown; it may be $NaCaAlSi_2O_7$, or $NaAl_3SiO_7$, or a more complex type.

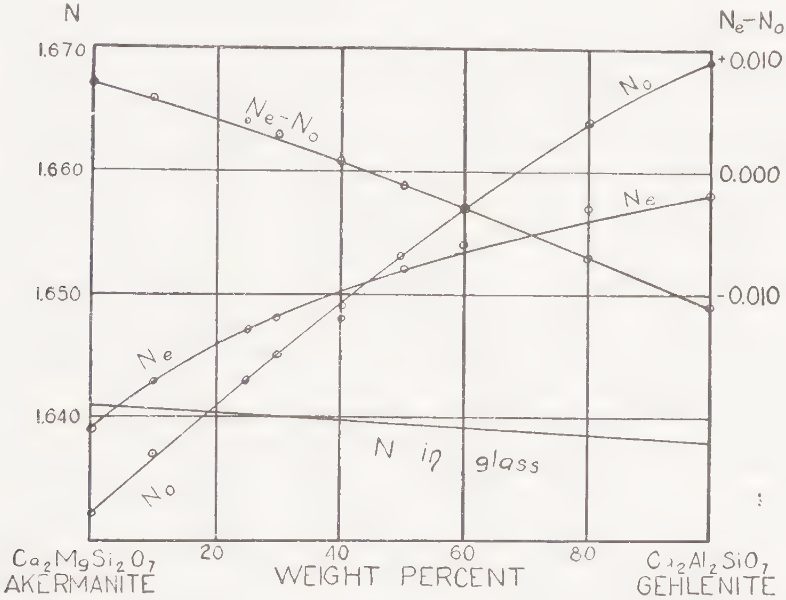

FIG. 194.—Variations in composition and optic properties in the akermanite-gehlenite series. (Based on data of Ferguson and Buddington: *Am. Jour. Sci.*, CC, 1920, p. 131.)

The chief constituents of most natural melilites are akermanite and gehlenite, which are mutually soluble in all proportions. Other molecules in natural melilite, never dominant and usually very subordinate, seem to include sodium melilite, iron-gehlenite ($Ca_2Fe'''_2SiO_7$) and iron-akermanite ($Ca_2Fe''Si_2O_7$). Excess silica is also common.

Akermanite is positive; gehlenite is negative; therefore certain mix-crystals are isotropic, the indices N_o and N_e being equal, as shown in Fig. 194.

Hardystonite ($Ca_2ZnSi_2O_7$) is tetragonal; crystals rare with good 001 cleavage and 100 and 110 parting. H. = 3–4. G. = 3.4. F. = 6. Gelatinizes with HCl. Uniaxial negative with $N_o = 1.672$ D, $N_e = 1.661$, $N_o - N_e = 0.011$. Color white. Found at Franklin, N. J., with willemite, rhodonite, etc. Very rare.

AKERMANITE ($Ca_2MgSi_2O_7$) is tetragonal with $c = 0.45$; crystals thin 001 tablets with 110 and 001 cleavages. H. = 5. G. = 3.18. F. = 1458° C. Gelatinizes with acid. Uniaxial positive with $N_o = 1.633$, $N_e = 1.639$, $N_e - N_o = 0.006$. Colorless. Index of glass = 1.641. Found only in slags and artificial melts.

Iron-akermanite ($Ca_2Fe''Si_2O_7$) is unknown in nature, but found nearly pure in slags, as at Salt Lake, with G. = 3.23, $N_o = 1.670$, $N_e = 1.658$, $N_o - N_e = 0.012$. *Justite* contains nearly 50 per cent $Ca_2FeSi_2O_7$ with nearly 35 per cent $Ca_2(Zn,Mn)Si_2O_7$ and has $N_o = 1.670$, $N_e = 1.657$, $N_o - N_e = 0.013$. Found in slags.

GEHLENITE TETRAGONAL $c = 0.40$ $Ca_2Al_2SiO_7$

PHYS. CHAR.—Crystals short prismatic with imperfect 001 and very poor 110 cleavages. H. = 5.5–6. G. = 3.04. F. = 1450° C. Gelatinizes with HCl.

OPT. PROP.—Uniaxial negative with $N_o = 1.669$, $N_e = 1.658$. $N_o - N_e = 0.011$. Color grayish green to brown; colorless in thin section. Index of glass = 1.638.

OCCUR.—A contact mineral in limestone at Vesuvius. Rare.

DIAG.—Resembles vesuvianite and zoisite, but zoisite is biaxial positive and vesuvianite has higher refringence and weaker birefringence.

Iron-gehlenite ($Ca_2Fe'''_2SiO_7$) is unknown alone, but found in natural melilites, slags and artificial melts to about 25 per cent. With [13] 7.76 Fe_2O_3 and 5.66 Al_2O_3, $N_o = 1.666$, $N_e = 1.661$, $N_o - N_e = 0.005$.

NEPHELITE GROUP

The nephelite group includes several orthosilicates of aluminum with sodium, potassium or lithium; the type formula is R_3O_4 in which R includes Si, Al and another base. Natural nephelite commonly contains not only $NaAlSiO_4$ but also some K, Ca and excess SiO_2. It is now demonstrated that the K in nephelite is in the molecule, $KAlSiO_4$. Bowen [14] believes that the Ca and excess silica are present in plagioclase molecules. The possibility that the silica is present merely as SiO_2, as urged by Foote and Bradley,[15] and the

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[13] A. F. Buddington: *Am. Jour. Sci.*, CCIII, 1922, p. 35.

[14] *Am. Jour. Sci.*, CLXXXIII, 1912, pp. 49 and 551; also CXCIII, 1917, p. 115.

[15] *Am. Jour. Sci.*, CLXXXI, 1911, p. 25.

Ca as $CaAlAlO_4$ (or a more complex molecule such as $NaCaAl_3SiO_8$, which equals $CaAlAlO_4 + NaAlSiO_4$) deserves further study. The chief minerals of the group are the following:

Nephelite	$c = .839$	$NaAlSiO_4$
Kaliophilite	$c = .838$	$KAlSiO_4$
Eucryptite		$LiAlSiO_4$

The following minerals are related to this group:

Microsommite	$2c = .837$	$(Na,K)_{10}Ca_4Al_{12}Si_{12}O_{52}SCl_4$?
Cancrinite	$2c = .818$	$(Ca,NaH)CO_3 \cdot 3NaAlSiO_4$?

NEPHELITE HEXAGONAL $c = 0.839$ $NaAlSiO_4$, etc.

COMP.—Artificial nephelite of theoretical composition is readily made, but natural nephelite contains usually about 5–20 per cent $KAlSiO_4$ with about 3–10 per cent of excess silica, and sometimes .5–2.5 per cent of CaO.

PHYS. CHAR.—Crystals thick prismatic terminated by the base, with indistinct $10\bar{1}0$ and difficult 0001 cleavages; often massive. H. = 5.5–6. G. = 2.55–2.65. The natural mineral fuses at about 4 to colorless glass; pure $NaAlSiO_4$ melts at 1526° C., after inversion at 1248° C. Gelatinizes with acids.

OPT. PROP.—Uniaxial negative; refringence always low and birefringence weak, but both vary appreciably, as follows:

$$N_o = 1.536\text{–}1.549 \quad N_e = 1.532\text{–}1.544 \quad N_o - N_e = 0.003\text{–}0.005.$$

The relations between these variations and variations in the composition are not yet established, but pure $NaAlSiO_4$ has $N_o = 1.537$, $N_e = 1.533$, $N_o - N_e = 0.004$, with G. = 2.619 at 21° C. Glass of the same composition has $N = 1.510$. $KAlSiO_4$ in nephelite must tend to slightly lower the indices and to slightly increase the birefringence since the pure substance has $N_o = 1.532$, $N_e = 1.527$, $N_o - N_e = 0.005$. Bowen has shown[16] that $CaAl_2Si_2O_8$ (or $CaAlAlO_4 + 2SiO_2$?) in nephelite has almost no effect upon the mean index, but decreases the birefringence to zero (at 23 per cent $CaAl_2Si_2O_8$) and then increases it to .002, the sign being positive (at 35 per cent $CaAl_2Si_2O_8$—the maximum). In natural nephelite the amount of CaO is not known to exceed 2.5 per cent, while 35 per cent

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[16] *Am. Jour. Sci.*, CLXXXIII, 1912, p. 566.

$CaAl_2Si_2O_8$ means about 7 per cent CaO. Therefore the chief effect of CaO in natural nephelite is to decrease the birefringence. The indices of nephelite may be increased[17] about .002 by heating the mineral to 800° C.

Colorless or tinted by impurities. Luster vitreous to greasy. Colorless in thin section.

Inver.—Pure artificial nephelite inverts at 1248° C. to an isometric form;[18] on rapid cooling the reverse change does not occur, but the isometric substance changes at about 690° C. to a metastable triclinic(?) form known as *carnegieite*, which always shows complicated multiple twinning, has G. = 2.513 at 21° C. and fuses at 1526° C. Carnegieite is biaxial, negative, with $2V = 12°–15°$ and $N_g = 1.514$, $N_m = 1.514 -$, $N_p = 1.509$, $N_g - N_p = 0.005$. Colorless. The inversion temperature is higher (at least 1325°–1350° C.) for natural nephelites.

Alter.—Nephelite alters in various ways; it may change to a mass of fibrous zeolites (natrolite, sometimes with thomsonite or phillipsite), or to analcite or sodalite; very frequently it alters to cancrinite, this change occurring first along cleavage cracks and fractures, and finally replacing the whole mass. The cancrinite often has uniform orientation which may be that of the original nephelite. Further, nephelite often changes in a similar way to mica, the laminæ being commonly parallel with the basal cleavage of the original mineral. The mica formed is a colorless variety of muscovite which has been called *liebenerite*, and, also, *gieseckite*. Calcite may form at the same time. More rarely nephelite alters to kaolinite, to garnet, or to a colloidal substance of unknown nature.

Occur.—Nephelite is found only in igneous rocks relatively high in soda and low in silica, such as nephelite syenite and phonolite. In such rocks it replaces more or less feldspar.

Diag.—Nephelite is distinguished from apatite and melilite by much lower refringence, giving no relief; sodalite is isotropic; scapolite has stronger birefringence and different cleavage; orthoclase is biaxial, has better cleavage, more twinning, and does not gelatinize with acids. Nephelite has somewhat distinctive alteration products.

KALIOPHILITE Hexagonal $c = 0.838$ $KAlSiO_4$

Comp.—Kaliophilite forms (at high temperatures) a continuous series of mix-crystals with nephelite, and the natural mineral commonly contains 5–20 per cent of $NaAlSiO_4$.

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[17] A. Zambonini: *Zeit. Kryst.*, LV, 1915, p. 302.

[18] N. L. Bowen and J. W. Greig: *Am. Jour. Sci.*, CCX, 1925, p. 204.

Phys. Char.—Crystals thick prismatic with imperfect $10\bar{1}0$ and 0001 cleavage (or parting?). H. = 6. G. = 2.56 (2.49–2.67). F. = about 1800° C. (pure). Gelatinizes with HCl.

Opt. Prop.—Uniaxial negative, the pure substance having $N_o = 1.532$, $N_e = 1.527$, $N_o - N_e = 0.005$. The natural mineral from Italy has $N_o = 1.537$, $N_e = 1.533$, $N_o - N_e = 0.004$. Kaliophilite glass has $N = 1.508$. Colorless.

Inver.—Changes to an orthorhombic form [14] at about 1540° C.; the latter is metastable at ordinary temperature and has been formed artificially at about 500° C. It shows very common twinning often of the aragonite type; it is biaxial, negative, with $2V = 39°$ and $N_g = 1.536$, $N_m = 1.535$, $N_p = 1.528$, $N_g - N_p = 0.008$. Colorless. It has been found in nephelinite from West Africa.

Alter.—May change to microsommite, and may be a product of alteration of leucite.

Occur.—Only in volcanic rocks relatively rich in potassa and low in silica.

Diag.—Very difficultly distinguishable from nephelite which is much commoner and has slightly higher indices of refraction.

Eucryptite ($LiAlSiO_4$) is hexagonal with distinct 0001 cleavage. G. = 2.67. Uniaxial negative with $N_o = 1.545$, $N_o - N_e$ = weak. Colorless. Found as an alteration product of spodumenite at Branchville, Conn.

Microsommite $\{(Na,K)_{10}Ca_4Al_{12}Si_{12}O_{52}SCl_4?\}$ is hexagonal with $2c = 0.837$. Crystals prismatic with perfect $10\bar{1}0$ and indistinct 0001 cleavages. H. = 6. G. = 2.45 ±. F. = 3.5. Gelatinizes with acids. Uniaxial positive with $N_o = 1.521$, $N_e = 1.529$, $N_e - N_o = 0.008$. Colorless. Found at Vesuvius, etc. Very rare. Differs from nephelite in sign and from quartz in its cleavages.

CANCRINITE Hexagonal $2c = 0.818$ $(Ca,NaH)CO_3 \cdot 3NaAlSiO_4$?

Phys. Char.—Crystals prismatic, rare, with perfect $10\bar{1}0$ cleavages. H. = 5–6. G. = 2.42–2.5. F. = 2 with intumescence. Effervesces and gelatinizes with acids.

Opt. Prop.—Uniaxial negative with $N_o = 1.515–1.524$, $N_e = 1.491–1.502$, $N_o - N_e = 0.023–0.029$. Color white or tinted; colorless in section.

Alter.—Rarely alters to natrolite.

Occur.—Apparently a primary constituent of certain sodic igneous rocks, associated with nephelite; also a common alteration product of nephelite.

Diag.—Distinguished from nephelite by much stronger birefringence, as well as by ready fusibility and effervescence; differs from scapolite in cleavage, from calcite in cleavage and much weaker birefringence, and from thomsonite by uniaxial character.

Sulphatic cancrinite [19] has $CO_2 = 3.18$ and $SO_3 = 4.65$, while $N_o = 1.509$, $N_e = 1.500$, $N_o - N_e = 0.009$. Colorless. Found in Colorado; very rare.

Davynite is a potassium-bearing cancrinite which is positive (or rarely negative) with $N_o = 1.518–1.520$, $N_e = 1.517–1.522$, $N_e - N_o = 0.000–0.003$. Colorless. Rare.

Natrodavynite is similar (with Na_2O and more CO_2) with $N_o = 1.522$, $N_e = 1.527$, $N_e - N_o = 0.007$. Colorless. Rare. A similar mineral [20] with CO_3 partly replaced by OH, SO_4 and Cl has: $N_o = 1.530$, $N_e = 1,535$, $N_e - N_o = 0.005$, G. = 2.46.

BERYL Hexagonal $c = 0.499$ $Be_3Al_2(SiO_3)_6$

Comp.—The formula is only an approximation; other elements often present include: Na, K, Li, Cs.

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[19] E. S. Larsen and G. Steiger: *Am. Jour. Sci.*, CXCII, 1916, p. 332.

[20] L. J. Spencer: *Min. Abst.*, II, 1924, p. 306.

Phys. Char.—Crystals prismatic with poor 0001 cleavage. H. = 7.5–8. G. = 2.63–2.91. F. = 1420° ± C. Insoluble in acids.

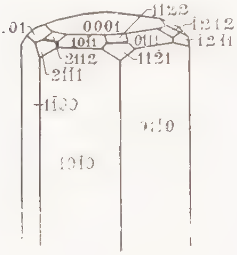


Fig. 195.—A crystal habit of beryl.

Opt. Prop.—Uniaxial negative, but some crystals have a very small optic angle, rarely as large as 10° (2E); in such cases the hexagonal form is due to twinning of three or six orthorhombic units as in aragonite. In cross sections the center of such twins may be uniaxial. The refringence and birefringence, as well as the density vary considerably with the tenor of alkalies, which reaches a maximum of at least 7 per cent. The range of known values follows:

$$N_o = 1.568\text{–}1.602,\ N_e = 1.564\text{–}1.595,\ N_o - N_e = 0.004\text{–}0.008.$$

The relation between the indices and the varying composition is shown in Fig. 196.

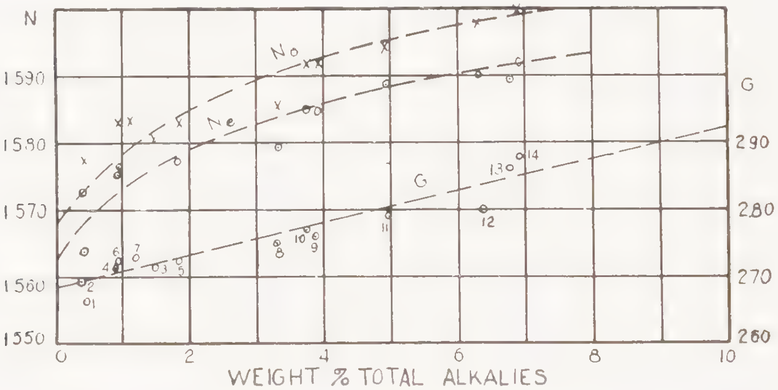


Fig. 196.—Variations of composition and optic properties in beryl.

Color green, blue, yellow, white, pink; the beryl with much alkali, especially cæsium, is usually pink. Luster vitreous, sometimes resinous. Colorless in thin section; more or less pleochroic in thick sections as follows:

	Emerald	Blue beryl	Yellow beryl	Pink beryl
X(E) =	sea green	blue	reddish yellow	pale pink
Z(O) =	yellowish green	greenish blue to colorless	golden yellow	colorless

In some cases the absorption formula is X < Z.

Alter.—Beryl alters rather easily to kaolin, the change beginning in fractures and making the mineral opaque and soft.

Occur.—In pegmatites, in tin lodes, and in mica schists.

Diag.—Differs optically from apatite in lower refringence and slightly stronger birefringence; also, in thick sections, in pleochroism. Beryl is harder than apatite and insoluble in acids. It also differs from apatite in mode of occurrence, and alters much more easily.

Bityite (silicate of Al, Ca, Li, H, etc.) is pseudohexagonal in basal plates or prismatic with distinct basal cleavage. H. = 5.5. G. = 3.05. F. = easy. Insoluble. Basal sections are divided into six sectors each normal to acute negative bisectrix. Each sector may show lamellar twinning parallel to a prism face. Extinction is at 30° on each side of the twinning plane. (−) 2V = small. $N_g < 1.64$, $N_m = 1.63$, $N_p > 1.62$, $N_g - N_p = 0.02 \pm$. Color yellowish or white. Found in pegmatite with tourmaline, lepidolite, etc. Differs from mica and prehnite in optic properties.

CORDIERITE (*Iolite*) Orthorhombic $Mg_2Al_4Si_5O_{18}$

$$a : b : c = 0.487 : 1 : 0.559$$

Comp.—By solid solution the SiO_2 may be increased. Natural cordierite commonly contains 0.5–3 per cent H_2O and 3–6 per cent FeO with minor amounts of Fe_2O_3 and alkalies.

Phys. Char.—Crystals short prismatic with large base; aragonite type of pseudohexagonal twinning common on 110 or 130. Distinct 010 and indistinct 100 and 001 cleavages. When partially altered the mineral becomes lamellar parallel to 001. H. = 7–7.5. G. = 2.57–2.66. Dissociates at about 1450° C. Partly decomposed by acids.

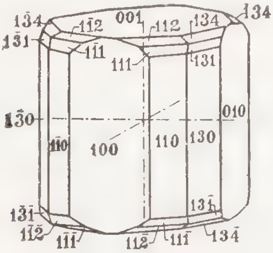


Fig. 197.—A crystal habit of cordierite.

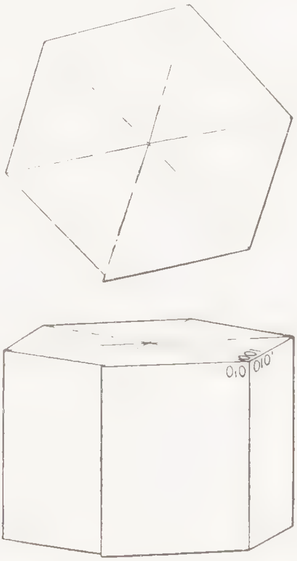
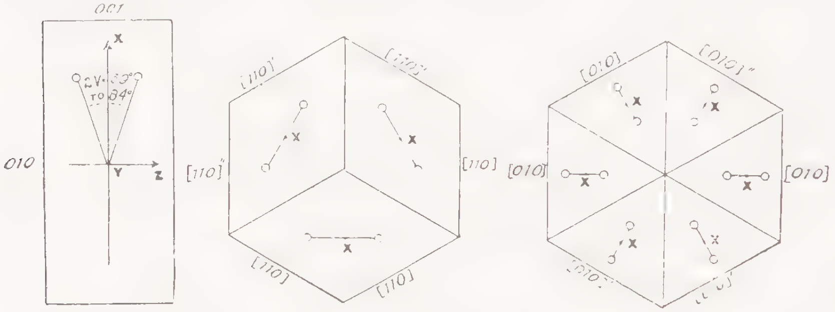


Fig. 198.—Pseudohexagonal cyclic twinning in cordierite.

Opt. Prop.—The optic plane is parallel to 100; the negative acute bisectrix X is normal to 001; the optic angle is quite variable and is reported to exceed 90° in rare cases, the sign then being positive; it may vary notably in different parts of a single crystal. Heat increases the optic angle very perceptibly. The dispersion is weak with $\rho < v$. Most cordierite has: (−) $2V = 40°–80°$, $N_g = 1.545 \pm .004$, $N_m = 1.543 \pm .004$, $N_p = 1.538 \pm .004$, $N_g - N_p = 0.008 \pm 0.002$. The known [21] limits of variation are as follows: $2V = 39°–84°$ (also to 99°), $N_g = 1.539–1.57$, $N_m = 1.536–1.562$, $N_p = 1.532–1.552$, $N_g - N_p = 0.003–0.011$ (also 0.03 [22]).



Figs. 199–201.—Optic orientation in a simple crystal of cordierite and in twins of cordierite.

Optically positive cordierite has been found in India; [23] the increase in the size of 2V (over X) from near 0° in artificial iron-free cordierite to 90°+ in very rare natural cordierite is *perhaps* due to increase in iron content.

With increase of specific gravity the optic angle decreases while the mean index of refraction increases.[24]

Color of natural cordierite is light to dark blue, smoky blue; rarely greenish, yellow, brown. Color and pleochroism usually entirely lacking in thin section, but in thick plates:

X = clear yellow, tinted with green or brown.
Y = dark violet, dark blue, dark brown.
Z = clear blue of various shades, yellow brown.

The absorption is always Y > Z > X in fresh material.

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[21] The measures of Offret (*Bull. Soc. Fr. Min.*, XIII, 1890, p. 628) are omitted because they vary too much from all others; they are $N_g = 1.599$, $N_m = 1.597$, $N_p = 1.592$.

[22] *Mineral Mag.*, XX, 1923, p. 146.

[23] I. C. Chacko: *Geol. Mag.*, III (LIII), 1916, 462. M. S. Krishnan: *Mineral Mag.*, XX, 1924, p. 248.

[24] L. Oppenheimer: *Inaug. Diss. Heidelberg*, 1914; *N. Jahrb. Min.*, 1915, I, p. 175.

Incl.—Cordierite of the plutonic rocks often contains inclusions of sillimanite, spinel, staurolite, zircon, apatite and dumortierite. The last three are often surrounded by pleochroic halos which may occur even in colorless cordierite. In these halos the color parallel to X is changed to deep lemon yellow, the refringence is slightly increased, and, unlike halos in other minerals, the birefringence is decreased. The halos disappear at red heat.

Cordierite of the volcanic rocks contains many vitreous inclusions of secondary origin accompanied by octahedrons of spinel, magnetite, etc. Cordierite in schists at granite contacts often contains carbonaceous inclusions regularly distributed, as in andalusite.

Alter.—Cordierite alters very readily, giving rise to many products of varied aspect, which have received many names. These secondary products consist of biotite, muscovite, chlorite, and isotropic substances. Cordierite when altered chiefly to mica with development of basal lamination is called *gigantolite*; if the lamination is lacking the name *pinite* is applied. Similarly, when the alteration product is chiefly chlorite it is called *chlorophyllite* when the basal lamination is present, and *prasiolite* when it is lacking.

Occur.—Cordierite is found in gneiss, in schists and slates modified by eruptive rock, especially granite, and in rock inclusions in volcanic rocks. It is also found in (endomorphosed?) igneous rocks rich in alumina and magnesia and with more than the feldspar ratio of silica. It is usually associated with quartz, orthoclase, albite, tourmaline, andalusite, sillimanite, staurolite, spinel, garnet, zircon, etc.

Diag.—Distinguished in thin section from quartz and orthoclase by inclusions (of sillimanite, staurolite, etc.), by pleochroic halos about zircon or dumortierite, and by the mode of formation of alteration products. Furthermore, the refringence of cordierite is distinctly higher than that of orthoclase, and quartz is uniaxial. Pleochroism and pleochroic halos are characteristic, if present. Perhaps the most satisfactory diagnostic is the symmetrical extinction in twins

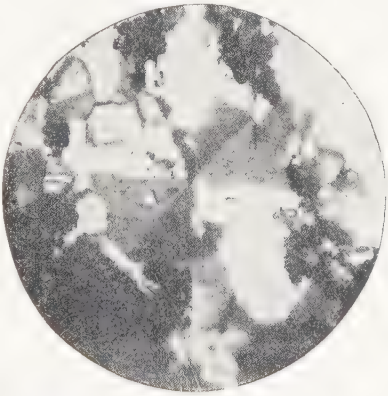

Fig. 202.—Photomicrograph of cordierite in thin section showing pseudohexagonal twinning.

at 30° from the twinning line with both parts of the twin perpendicular to the negative acute bisectrix (basal section).

Melanotekite ($Pb_3Fe_4Si_3O_{15}$) is orthorhombic with $a : b : c = 0.634 : 1 : 0.913$. Crystals prismatic with two unequal cleavages. H. = 6.5. G. = 5.7. F. = 2–2.5 with intumescence. Decomposed by HNO_3. Optic orientation unknown. (+) 2V = 67°, $\rho < v$, rather strong. $N_g = 2.31$, $N_m = 2.17$, $N_p = 2.12$, $N_g - N_p = 0.19$. Color black; in thin section intensely pleochroic with X = nearly colorless, Y = pale reddish brown, Z = deep reddish brown. Found in lead deposits in Sweden. Very rare.

Kentrolite ($Pb_3Mn_4Si_3O_{15}$) is orthorhombic with $a : b : c = 0.633 : 1 : 0.899$. Crystals prismatic with distinct 110 cleavages. H. = 5. G. = 6.19. F. = 2–2.5. Soluble in HCl. Optic plane is 010; X = *a*. (+) 2V = 88°, $\rho < v$, strong. $N_g = 2.31$, $N_m = 2.20$, $N_p = 2.10$, $N_g - N_p = 0.21$. Color dark reddish brown. In section strongly pleochroic in reddish brown with X < Y < Z. Found in manganese deposits in Sweden. Very rare.

Taramellite ($Ba_4FeFe_4Si_{10}O_{31}$) is orthorhombic (?), fibrous with cleavage parallel to fibers; parting normal to cleavage. H. = 5.5. G. = 3.92. Optic plane parallel to fibers and normal to cleavage; Z parallel to fibers. (+) 2E = 75° 40′, $\rho > v$, distinct. $N_g = 1.83$, $N_m = 1.774$, $N_p = 1.770$, $N_g - N_p = 0.06$. Color reddish brown with X = Y = flesh red, Z = blackish brown. Found in limestone near a contact. Very rare.

The following monoclinic silicates of Al or Fe‴ and Na or Li have been described elsewhere because of isomorphous relations with silicates of divalent bases:

Spodumenite ($LiAlSi_2O_6$), see the pyroxene group.
Jadeite ($NaAlSi_2O_6$), see the pyroxene group.
Acmite ($NaFeSi_2O_6$), see the pyroxene group.
Glaucophane $\{NaAlSi_2O_6 \cdot (Mg,Fe)SiO_3\}$, see the amphibole group.
Riebeckite ($NaFeSi_2O_6 \cdot FeSiO_3$), see the amphibole group.
Torendrikite ($NaFeSi_2O_6 \cdot MgSiO_3$), see the amphibole group

PETALITE MONO. $a : b : c = 1.153 : 1 : 0.744$ $\beta = 67° \ 34'$ $LiAlSi_4O_{10}$

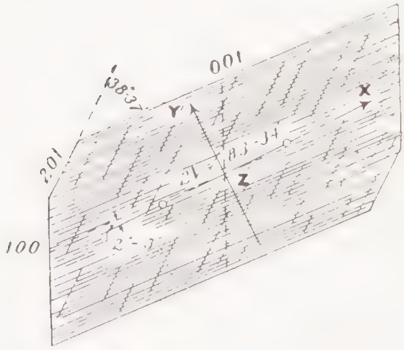

FIG. 203.—Optic orientation of petalite.

PHYS. CHAR.—Crystals 010 tablets or elongated parallel to *a*. Perfect 001 and easy 201 cleavages. H. = 6. G. = 2.4. F. = 5 (phosphorescent). Soluble in HF, but not in ordinary acids.

OPT. PROP.—The optic plane is normal to 010; X ∧ *a* (= 001 cleavage) = 2° to 8° in acute angle β. Weak crossed dispersion with $\rho < v$, weak. (+) 2V = 83° 34′, $N_g = 1.516$, $N_m = 1.510$, $N_p = 1.504$, $N_g - N_p = 0.012$. Red, green, or white; colorless in thin section.

INVER.—Petalite from Elba becomes uniaxial at 1000°–1100° C.; then becomes isotropic at 1200° C.; at 1370° forms a glass with G. = 2.29 and N = 1.495.

Occur.—In pegmatites and some ore deposits, often associated with spodumenite, tourmaline, etc. Rare.

Diag.—The extinction nearly parallel to the best cleavage which has a negative direction, with large positive optic angle, and an angle of 141° between two unequal cleavages, is characteristic.

SAPPHIRITE (*Sapphirine*) Mono. $a : b : c = 0.731 : 1 : 1.412$ $Mg_5Al_{12}Si_2O_{27}$
$\beta = 68° 33'$

Phys. Char.—Crystals 010 tablets with rare prism faces. No good cleavage. H. = 7.5. G. = 3.3–3.5. F. = 7. Insoluble in acids.

Opt. Prop.—The optic plane is 010; $Z \wedge c = +8°$ (Lacroix); $= 15°$ (Walker[25]). Very distinct inclined dispersion with $\rho < v$. (−) 2V = 69°. $N_g = 1.708–1.734$, $N_m = 1.707–1.733$, $N_p = 1.704–1.729$,[26] $N_g - N_p = 0.003–0.006$. Color pale blue or green. Pleochroism weak in thin section, strong in thick plates, with: X = colorless, greenish yellow, pale smoky brown; Y = dark blue, dark greenish blue, sapphire blue; Z = dark blue, greenish blue (yellowish), sapphire blue.

Occur.—In mica schists and gneisses with spinel, sillimanite, pale green hornblende, etc.; also with cordierite, kornerupite and anorthite. Rare.

Diag.—Differs from corundum by its biaxial character, from lazulite by the weak birefringence, from cyanite, clintonite, and blue amphiboles by the lack of cleavage, and from colored cordierite by the higher refringence and density.

Didymolite ($Ca_2Al_6Si_9O_{29}$) is monoclinic with $a : b : c = 0.60 : 1 : 0.287$, $\beta = 74°$. Crystals with 010, 110, 011, always twinned on 110, sometimes also on 010. Fair 010 and 110 cleavages. H. = 4.5. G. = 2.71. F. = diff. Insoluble except in HF. Optic plane is 010; $X \wedge c = 40°$. (−) 2V = 78°–87° 30′, $\rho > v$, $N_m = 1.501$, $N_g - N_p = 0.015$. Color dark gray. Colorless in section. Found in limestone near nephelite syenite in Siberia. Very rare.

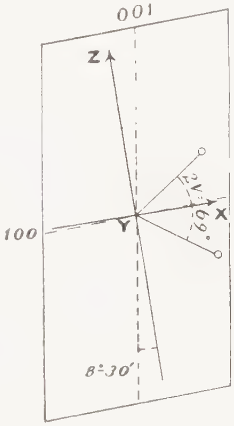

Fig. 204.—Optic orientation of sapphirite.

Tinzenite[27] ($CaMn'''AlSi_2O_8$) is monoclinic, platy with perfect 100 cleavage. Optic plane is 010; Z near *c*. (−) 2V = 63°, $N_g = 1.704$, $N_m = 1.701$, $N_p = 1.693$, $N_g - N_p = 0.011$. Color yellow, with X = pale yellowish green, Y = pale greenish, Z = colorless. Found in ore deposits. Very rare.

FELDSPAR GROUP

The feldspars are far more important as rock constituents than any other group of minerals; in fact, they may be compared in importance in igneous rocks with all other groups combined, since they constitute nearly 60 per cent of such rocks, and serve as the basis of their classification.

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[25] Walker and Collins: *Rec. Geol. Surv. India*, XXXVI, 1907, p. 1.

[26] C. H. Warren: *Am. Jour. Sci.*, CLXXXIII, 1912, p. 271.

[27] J. Jakob: *Schweiz. Min. Pet. Met.*, III, 1923, p. 227.

Summary.—The description of the feldspar group is so long that the following summary of the chief features may be useful.

In composition the feldspars are silicates of aluminum with potassium, sodium or calcium (rarely barium). The chief types are $KAlSi_3O_8$ (orthoclase or microcline), $NaAlSi_3O_8$ (albite) and $CaAl_2Si_2O_8$ (anorthite). Natural crystals of orthoclase or microcline usually contain 10 to 20 per cent of $NaAlSi_3O_8$. The albite and anorthite molecules form mix-crystals or crystal solutions in all proportions, which are called plagioclase; these also contain 5 to 15 per cent of $KAlSi_3O_8$ in most cases.

Crystals of orthoclase are monoclinic and those of plagioclase are triclinic, but the forms are nevertheless very similar with angles differing only 3° or 4°. All feldspars have good cleavages parallel to 001 and 010, making an angle of 90° in orthoclase and 93° 34′ to 94° 12′ in plagioclase. The basal cleavage is distinct and easily obtained; the other is slightly less distinct. Still other cleavages exist only in traces. The feldspars exhibit many types of twinning; in general, orthoclase twins consist of only two (rarely three) parts, while microcline and plagioclase twins are multiple and lamellar, microcline showing a fine cross-grating of twinning lines. The specific gravity of ordinary feldspars ranges from 2.5 to 2.8, and the hardness from 6 to 6.5. Fusion occurs at 1200° to 1550° C. Except for anorthite, ordinary feldspar is insoluble in HCl.

Optically the feldspars have low relief (1.52 to 1.58), weak birefringence (0.006 to 0.013) and weak dispersion; they are all biaxial and of large optic angle except for one type of orthoclase; the sign is negative except in certain types of plagioclase. The extinction angles in sections of any known orientation are very useful in distinguishing between the various feldspars; some of the most important are given in Fig. 205. Feldspars are naturally colorless and glassy, but are often clouded by fractures and stained by impurities of various kinds.

The alteration of feldspars is usually a process of hydration and may lead to the formation of sericite, kaolinite, zeolites, or other similar minerals. Many other kinds of alteration products are known, depending on the conditions of temperature or pressure, or types of solutions to which the feldspars have been subjected. Feldspars are less stable than quartz, but more stable than olivine, nephelite, etc.

Chemical Composition.—The feldspars, aside from the rare and relatively unimportant types containing barium, belong to a three-component system whose three molecules are $KAlSi_3O_8$ (the orthoclase molecule = Or), $NaAlSi_3O_8$ (albite = Ab), and $CaAl_2Si_2O_8$ (anorthite = An). It is now fully demonstrated that both natural and artificial melts which contain Ab and An in any proportions can crystallize completely to form one type of homogeneous crystals. That is, Ab and An are mutually soluble in all proportions in the crystal state, as well as in the liquid state. The entire albite-anorthite series forms the mineral species known as plagioclase, which is an unexcelled example of complete isomorphism. All proportions of Or and Ab seem to occur in homogeneous crystals in rocks, but albite also crystallizes frequently in the presence of orthoclase. Although natural crystals rich in both Or and An are known, the simultaneous crystallization of plagioclase and orthoclase is very common in nature. Crystals containing several different proportions of orthoclase and

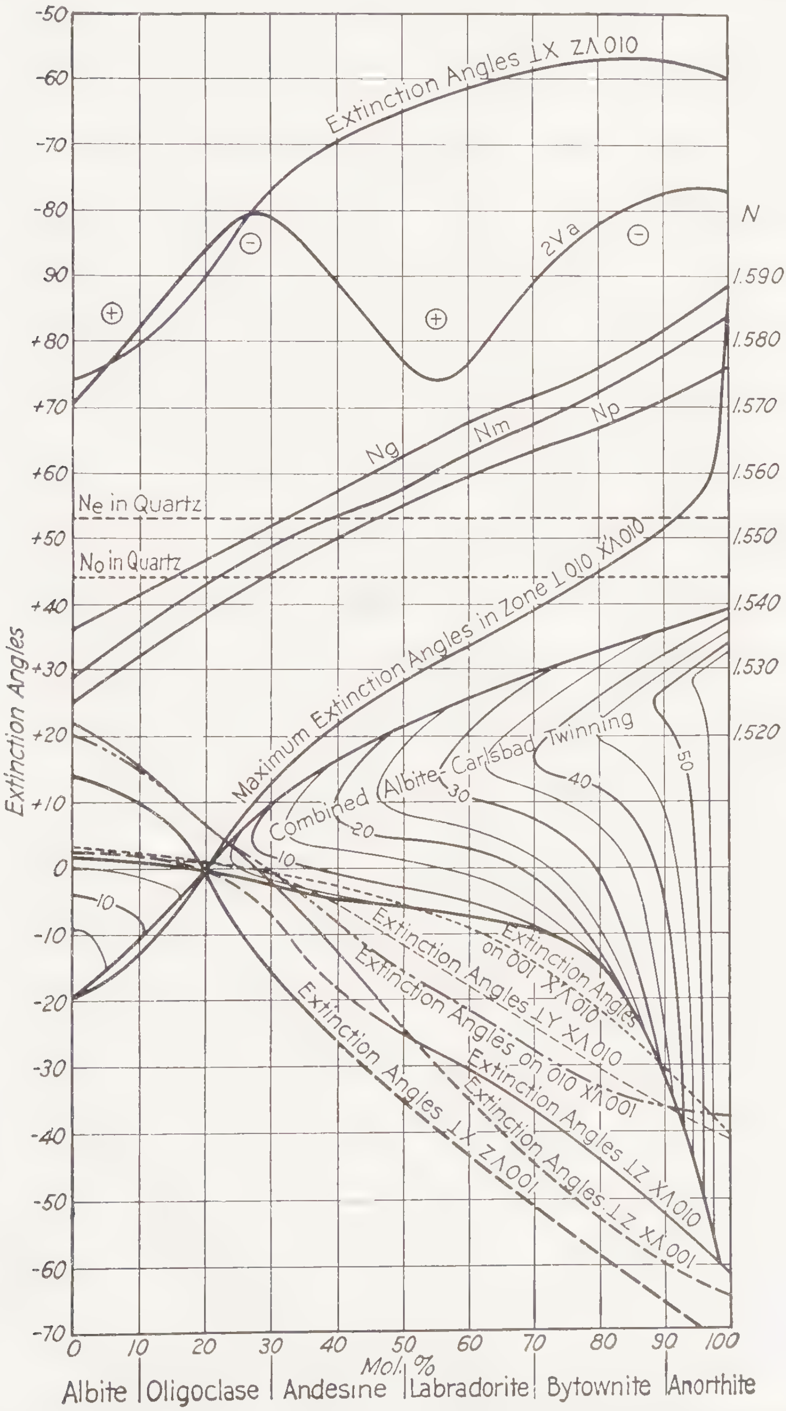

FIG. 205.—Diagrammatic summary of the more important optic properties of plagioclase. (Modified from Wright.)

the barium feldspar (celsian = Cn) have been found in nature and it is probable that they represent another continuous series of crystal solutions, Or and Cn being miscible in all proportions.

The chemical compositions of the pure molecules and crystals containing two molecules in certain simple ratios are given in the following table:

Molecule	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	BaO
Cn	32.0	27.2	....	....	....	41.8
$Or_{67}Cn_{33}$	51.6	21.9	....	....	10.1	16.4
Or	64.7	18.4	....	....	16.9	
$Or_{80}Ab_{20}$	65.6	18.5	....	2.4	13.5	
$Or_{50}Ab_{50}$	66.8	18.9	....	5.9	8.4	
$Or_{20}Ab_{80}$	68.0	19.2	....	9.4	3.4	
Ab	68.8	19.4	....	11.8		
$Ab_{80}An_{20}$	63.3	23.1	4.3	9.3		
$Ab_{60}An_{40}$	58.1	26.6	8.4	6.9		
$Ab_{50}An_{50}$	55.6	28.3	10.4	5.7		
$Ab_{40}An_{60}$	53.0	30.0	12.4	4.6		
$Ab_{20}An_{80}$	48.0	33.4	16.3	2.3		
An	43.2	36.7	20.1			

Again excluding the rare types containing barium, nearly all natural feldspars contain appreciable amounts of a third component in addition to the two chief components.[28] Therefore, while the feldspars of rocks are commonly described as orthoclase (or microcline, or anorthoclase) and plagioclase, they are really not one- or two-component substances as indicated by these names, but are three-component crystal solutions. This is well illustrated in Fig. 206, which shows the results of plotting nearly a thousand analyses of feldspars in a three-component diagram. To the original diagram prepared by Alling the writer has added the lines which express his views of the approximate limits of stable solid solutions at various temperatures. Crystals of composition in the intermediate zone are believed to be stable at high temperatures and unstable, or metastable, at low temperatures. In some cases they seem to remain homogeneous (metastable) at low temperatures; in other cases they seem to separate into distinct, but intimately intergrown, parts on cooling, the whole mass then being known as "*perthite*." This change from a single space lattice to two intergrown space lattices of different kinds may occur even without separation into distinct parts, visibly different, as shown by the tests of Kozu and Suzuki,[29] who found that X-ray patterns from *moonstone* indicated two space lattices at ordinary temperatures (one corresponding with orthoclase and the other with albite), and that these approach each other above 500° C. and coalesce at high temperatures.

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[28] Besides the three chief components some feldspars contain very small amounts of still other molecules, notably, $RbAlSi_3O_8$, $CsAlSi_3O_8$, $LiAlSi_3O_8$, $Na_2Al_2Si_2O_8$(?), etc. A strontium feldspar has been made artificially.

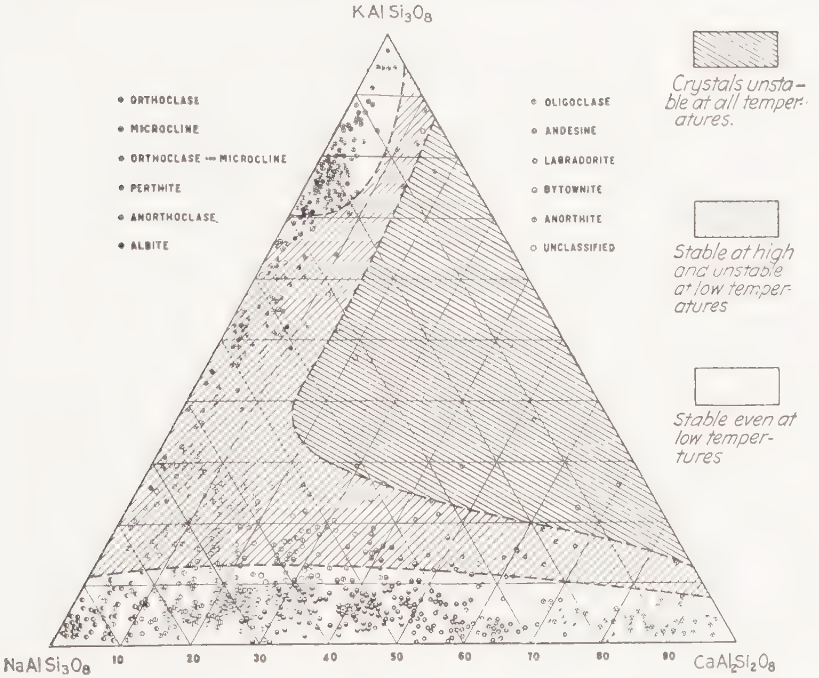

FIG. 206.—Variations in composition of feldspars. (After H. L. Alling: *Jour. Geol.*, XXIX, 1921, p. 193. Stability areas added by the author.)

CRYSTAL FORM.—The similarity of crystal form of all the feldspars, both monoclinic and triclinic, is shown in the following table. Here, and in other tables which follow, the composition is commonly expressed in terms of the chief feldspar molecules which are: anorthite ($CaAl_2Si_2O_8$ = An), albite ($NaAlSi_3O_8$ = Ab), orthoclase ($KAlSi_3O_8$ = Or), and celsian ($BaAl_2Si_2O_8$ = Cn).

Feldspar crystals are often short prismatic in habit, somewhat flattened parallel to 010, as in Figs. 207–210; they are also frequently elongated parallel to *a*, the crystals then appearing to be prismatic through development of 001 and 010, the real prism faces, 110, being

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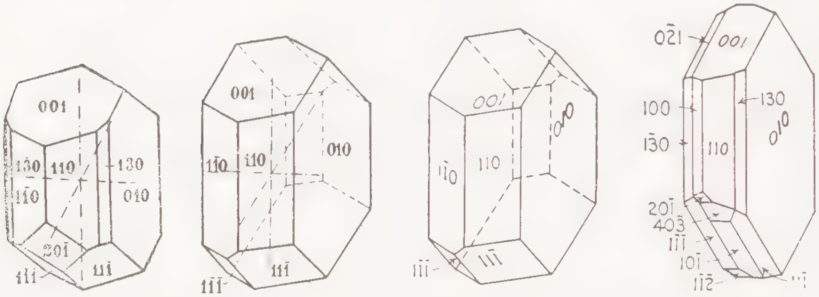
[29] *Sci. Rep. Tohoku Univ. Sendai*, III, 1, 1921, p. 19.

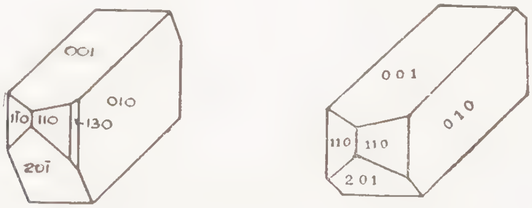
CRYSTALLOGRAPHY OF THE FELDSPARS

Name	$a:b:c$	α	β	γ	001 ∧ 010	Approx. Comp.
Celsian........	0.657 : 1 : 0.554	90°	115° 2′	90°	90°	Cn
Hyalophane...	0.6584 : 1 : 0.5512	90°	115° 35′	90°	90°	(Or,Cn)
Orthoclase.....	0.6586 : 1 : 0.5559	90°	116° 3′	90°	90°	Or
Microcline[30]...	0.6637 : 1 : 0.5546	89° 19′	115° 50′	92° 10′	89° 43′	Or
Anorthoclase...	0.6466 : 1 : 0.5522	90° 30′	116° 18′	90 ±	90 ±	(Ab,Or)
Albite[1]	0.6330 : 1 : 0.5573	94° 3′	116° 2[illegible]′	[illegible]	93° 34′	Ab
Oligoclase.....	0.6322 : 1 : 0.5525	93° 31′	116° 26′	89° 31′	93° 42′	$(Ab_{80}An_{20})$
Andesine	0.6355 : 1 : 0.5517	93° 27′	116° 15′	89° 55′	93° 50′	(Ab[illegible]An[illegible])
Labradorite....	0.6377 : 1 : 0.5547	93° 26′	116° 6′	90° 15′	93° 57′	$(Ab_{40}An_{60})$
Bytownite.....	....	93° 22′	116° 0′	90° 41′	94° 4′	$(Ab_{20}An_{80})$
Anorthite[31]	0.6352 : 1 : 0.5505	93° 5′	115° 54′	91° 54′	94° 12′	An



FIGS. 207 210.—Simple crystal habits of feldspar.

quite small, as shown in Figs. 211, 212. Feldspar microlites are usu-



FIGS. 211-212.—Feldspar crystals elongated parallel to the axis a.

ally of the form just described; when somewhat larger they may be thin lamellæ parallel to 010, as in Figs. 213, 214.

Anorthoclase is commonly elongated parallel to the vertical axis.

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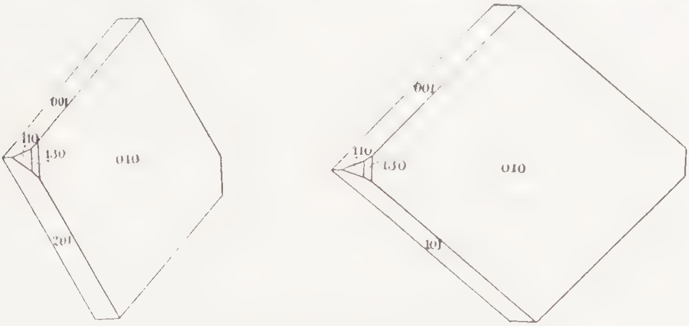
[30] O. B. Böggild: *Zeit. Kryst.*, XLVIII, 1911, p. 471.

[31] E. Schmidt: *Chemie der Erde*, I, 1919, p. 351.

The albite-anorthite series of mix-crystals is known collectively as plagioclase; it is distinctly triclinic, yet the angles α and γ vary only a little from 90°. The forms are therefore very similar to those of the monoclinic feldspars. Plagioclase is sometimes elongated parallel to *b*, a condition commonly found in the *pericline* variety of albite; when twinned on the axis *b*, the units are thin lamellar and produce striations on 100 and 010, which may be found in any kind of plagioclase.



FIGS. 213-214.—Feldspar microlites flattened parallel to 010.

TWINNING.—The feldspars are all subject to very common twinning. The usual type in monoclinic feldspar is known as Carlsbad twinning; other types include the Manebach and Baveno. In triclinic feldspars the albite type of twinning is nearly always present and other types are not rare, especially the pericline.

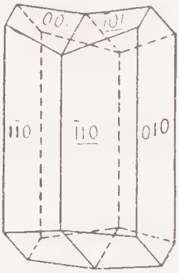


FIG. 215.—Contact Carlsbad twin of albite.

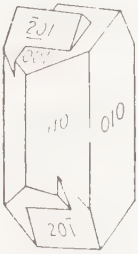


FIG. 216.—Partial penetration Carlsbad twin of orthoclase.

In the Carlsbad form the twins are united by some plane, usually 010, parallel to the vertical axis, while the twinning axis may be considered to be *c*, or a line normal to 100. Such twins may be merely in contact, as in Fig. 215, or show more or less interpenetration, as in Fig. 216. In a thin section of a Carlsbad twin the 010 cleavage in one part is parallel with that in the other part, and the basal cleavages form oblique angles with one another. If the section is normal to 010, the 001 and 010 cleavages will be exactly, or very nearly, at right angles. Carlsbad twins are almost invariably composed of only two parts; this fact is of considerable importance in distinguishing megascopically, and in a rapid preliminary way microscopically, between orthoclase and plagioclase. Multiple lamellar twinning is almost always present in the latter.

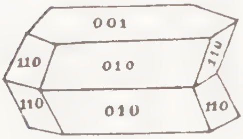


Fig. 217.—Manebach twin of orthoclase.

The Manebach type (Fig. 217) has the basal plane as the twinning plane, and also, usually, as the composition face. The 001 cleavages of one part are parallel to the same cleavages of the other part. The same is true of the 010 cleavages.

In Baveno twins the twinning axis is normal to 021 which is the composition face. Such twins are elongated parallel to *a* and often flattened parallel to 001. In the absence of flattening, they are nearly square in cross section as seen in Fig. 218, since 001 ∧ 021 is nearly 45°, being 44° 56′ in orthoclase and 46° 46′ in albite. Sections across such twins present square or rhombic outlines, the cleavages being parallel to the sides, and the twinning line being a diagonal from corner to corner, as shown in Fig. 219.

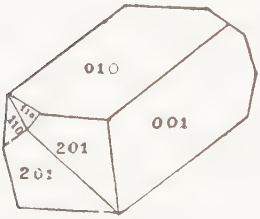


Fig. 218.—Baveno twin of orthoclase.

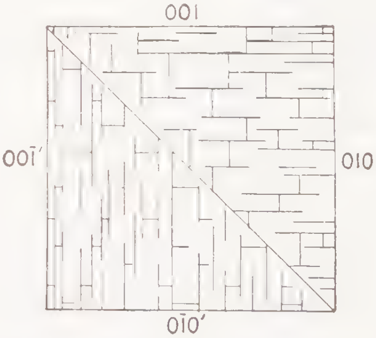
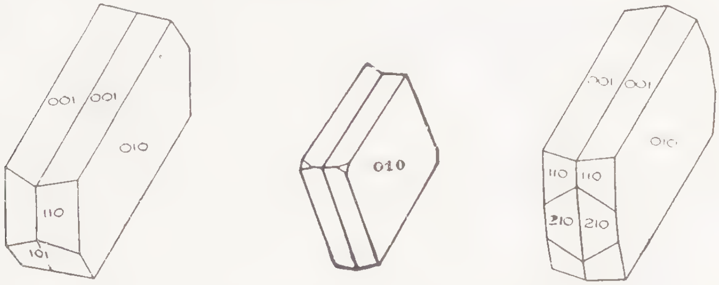


Fig. 219.—Section of a Baveno twin normal to the axis *a*.

In plagioclase, the albite and pericline types of twinning are very important. In the former, the composition face and twinning plane are both 010. Simple albite twins are represented in Figs. 220–222. This type of twinning is nearly always polysynthetic and lamellar, producing striations on 001 parallel to 010; it becomes parallel growth.

and is therefore optically invisible, in orthoclase, since the latter is monoclinic, and the albite twinning axis is consequently an axis of binary symmetry in it. Albite twinning is characteristic of plagioclase, in which it is rarely lacking.



FIGS. 220–222.—Simple albite twins in plagioclase feldspar.

In pericline twins the twinning axis is the axis *b*, while the composition face is the "*rhombic section*," which is the section made by a plane passing through the crystal parallel to *b* in such a direction that its intersections with the prism faces make an equilateral oblique-angled parallelogram or rhombus. The position of this rhombic section and the consequent direction of the twinning bands on 010 change rapidly with small changes in the value of γ. In 010 these twinning bands vary from parallel to the basal cleavage in one type of andesine, to an angle of plus 13° with 001 in albite and to minus 18° with 001 in anorthite, as shown in Fig. 224. Except rarely in

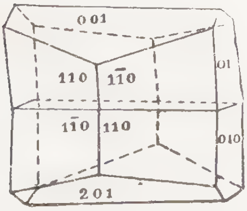


FIG. 223.—Simple pericline twin in albite.

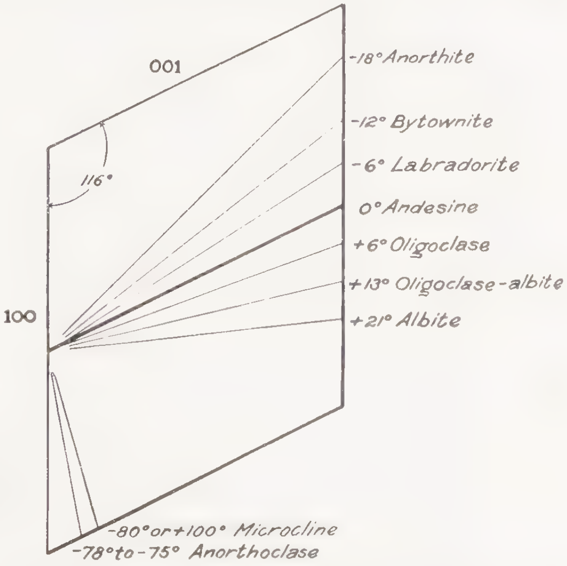


FIG. 224.—Position of composition face of pericline (and microcline) twinning in triclinic feldspars.

albite, pericline twinning is multiple, fine lamellar, and invisible without the microscope.

In microcline, and apparently in anorthoclase, a similar type of twinning exists with a composition face which is not a rhombic section, but makes a very large angle with 001 as shown in Fig. 224. Microcline is characterized by the nearly constant presence of two intersecting sets of fine lamellar twinning, any single twinning band usually tapering out in both directions, one set being albite twinning and the other microcline twinning. Anorthoclase usually has a similar quadrillage, though it is less distinct, being extremely fine and poorly defined. In anorthoclase one set of twinning lines is of the albite type; the other is either pericline twinning at − 4° to − 8° with 001, or microcline twinning at − 75° to − 78° with 001.

Plagioclase very often exhibits Carlsbad twinning, with or without albite twinning; other types, which are found less commonly in plagioclase, include Manebach and Baveno twinning.

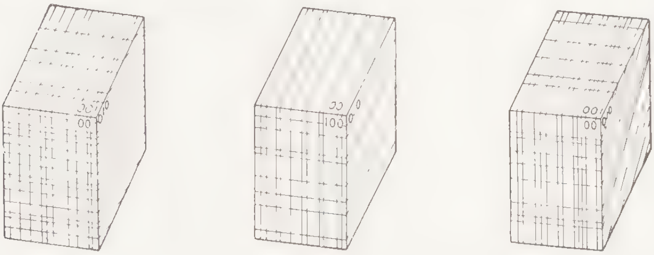
In thin section there is not much difference between the appearance of the various types of multiple twinning in the various feldspars, but, as a generalization, it may be said that multiple albite twinning lines are usually fine and far apart in albite, clear and of regular width in oligoclase, one set being wide and the other very fine, clear and well defined in labradorite, but of varying widths, and broad and regular in anorthite. Pericline twinning bands are often present only in certain ones of the albite bands; pericline twinning also occurs without albite twinning; therefore, it is important to note the microscopic distinctions between the two types which may be summarized as follows:

Albite twinning	Pericline twinning
Very common	Not rare
Parallel to 010 cleavage	At an angle of 0° to 21° with 001 cleavage
Parallel to Carlsbad twinning	At 0° to 21° with (rare) Manebach twinning
Negative elongation (except in anorthite)	Elongation ±

Albite and especially pericline twinning bands are so fine that they are frequently invisible without the microscope; their positions in simple crystals are shown in Fig. 225 for albite, Fig. 226 for andesine, and Fig. 227 for anorthite. The front face, 100, is rarely seen in nature, being replaced by prism faces.

As a brief summary statement it may be said that orthoclase often occurs in simple twins, but never in polysynthetic twins; microcline is (nearly) always polysynthetically twinned in two directions giving a fine grating structure between crossed nicols; plagioclase is nearly always multiply twinned on the albite law.

The study of feldspars by means of the Federoff universal stage has resulted in the discovery of still other types of twinning in them, and has led to the following classification[32] of all sorts of feldspar twinning.



FIGS. 225–227.—Albite twinning and pericline twinning striations on the pinacoid faces of albite (225), andesine (226), and anorthite (227); albite striations are vertical and pericline striations are horizontal on 100. Acline twinning striations on all plagioclases have the same position as pericline striations on andesine.

1. *Normal twins*, in which the twinning axis is normal to the composition face which is an important crystal face, namely, 010 in albite twinning, 001 in Manebach twinning, 021 in Baveno twinning, and 100 in twinning expected, but not yet found.

2. *Parallel twins*, in which the twinning axis is parallel to the composition plane, which may be a crystal face or vary notably from such a face. For example, the twinning axis is *c* and the composition face is 010 in " Carlsbad A " twinning; the twinning axis is *c* and the composition face is 100 or near that face in " Carlsbad B " twinning; the twinning axis is *b* and the composition face is 001 or within 20° of that face in the zone parallel to *b* in pericline twinning.

3. *Complex twins*, which consist of aggregates showing both normal and parallel twins having the same composition face. For example, a crystal may have Carlsbad A and also albite twinning; the composition face being 010 for each, the aggregate is a " complex " twin. Furthermore, it is customary to designate the first part as 1, the part in normal twinning relation with it as 1′, the part in parallel twinning relation with it as 2 and the part in normal twinning relation with 2, as 2′, which is in parallel twinning relation with 1′. In some cases such groups may be incomplete, showing only 1 and 2′, or 1′

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[32] See L. Duparc and M. Reinhard; *Mem. Soc. Phys. Hist. Nat. Genève*, XL, 1924, fasc. 1, for an elaborate treatise on the feldspars, based, in large part, on the work of Federoff.

and 2. Expressed in another way, such incomplete groups may be considered parallel twins in which the twinning axis is parallel to the composition face, but normal to the position of the twinning axis of the type of parallel twinning involved in a corresponding complete group. For example, a part 1 may be twinned on 010 with 1′ (albite type), and twinned on *c* with 2 (Carlsbad A) the part 2 being twinned on *c* with 2′ (albite type), all parts having 010 as the composition plane. In the absence of some parts, one may consider that part 1 is twinned with part 2′ on an axis in 010 normal to *c*, or part 1′ with 2 on the same axis.

The different kinds of twinning in feldspars are summarized in the following table:

Twinning Axis	Comp. Face	Name	Remarks
I. NORMAL TWINNING			
⊥010	010	Albite	Usually multiple; very common
⊥001	001	Manebach	Usually simple; not rare
⊥021	021	Baveno	Usually simple; not rare
II. PARALLEL TWINNING			
c	010	Carlsbad A	Usually multiple; very common; often associated with albite type
c	100	Carlsbad B	Composition face varies somewhat in the zone parallel to *c*
a	001	Ala A	Usually simple; often associated with Manebach twinning
a	010	Ala B	Often associated with albite twinning
b	001	Acline A	Associated with Manebach twinning
b	001±	Pericline	Alone or with albite twinning
III. COMPLEX TWINNING			
c and ⊥010 *or* ⊥*c* in 010	010	Albite— Carlsbad A	Common; may be multiple or have only 1, 2 and 2′, or only 1 and 2′
a and ⊥010 *or* ⊥*a* in 010	010	Albite— Ala B	Not common
a and ⊥010 *or* ⊥*a* in 010	001	Manebach— Ala A	Not common
b and ⊥001 *or* ⊥*b* in 001	001	Manebach— Acline A	Not very rare in labradorite and related plagioclases

It may be added that all sorts of combinations of the various types of twinning are found, such as Carlsbad with pericline, albite with Baveno, etc. The term "complex" twinning should be restricted to aggregates of two types having the same composition face.

Studies of the relative abundance of the various types of twinning show that those with 010 as the composition plane are decidedly most frequent, followed by the pericline type. In microlites, Carlsbad alone or Carlsbad-albite is as common as albite alone, so that determinations based on microlites should be checked carefully.

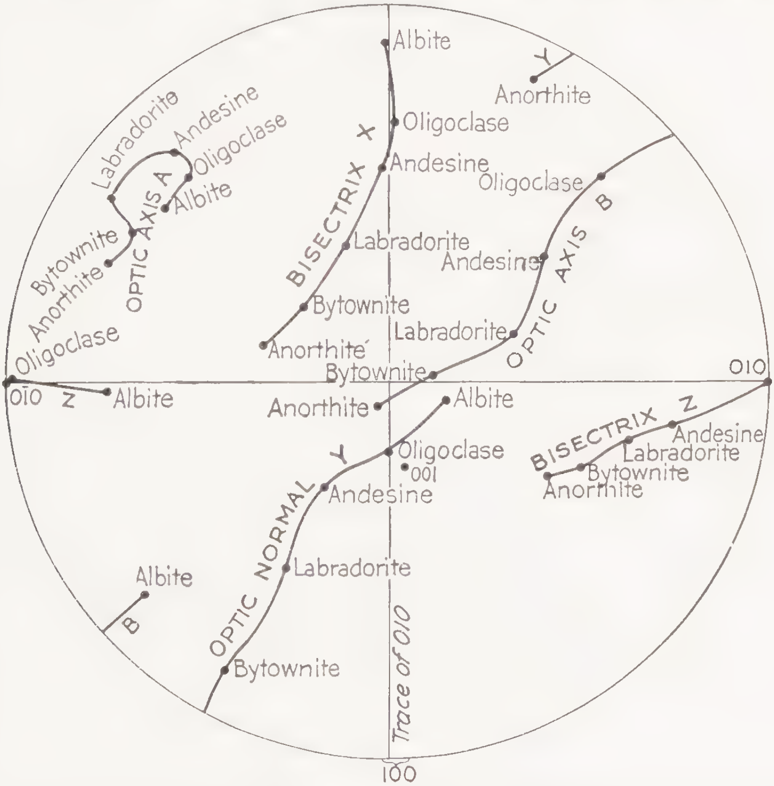

FIG. 228.—Stereographic projection of the optic elements in plagioclase on a plane normal to the axis *c*. (After Duparc and Reinhard.)

OPTIC PROPERTIES.—All feldspars are biaxial and colorless in thin section. The optic orientation is different in the various kinds of feldspar, and is extremely important in distinguishing between them microscopically. Most of the feldspars have a large optic angle, the sign of which is either positive or negative. The dispersion varies in different types, but is always too weak to give visible effects in thin section (incomplete extinction normal to an optic axis is due in part to dispersion). The refringence is low in all kinds of feldspar, and the birefringence is weak, except in anorthite, in which it is moderate.

Optic Orientation.—In potash feldspar (adularia and microcline) the optic plane is nearly or exactly normal to 010, and nearly parallel with the base, 001, while Z is nearly or exactly normal to 010, X is nearly parallel to 001 and Y is nearly normal to 001. However, adularia inverts at about 900° C. to a high temperature form in which the optic plane is 010 and X makes an angle of about + 5° with *a*.

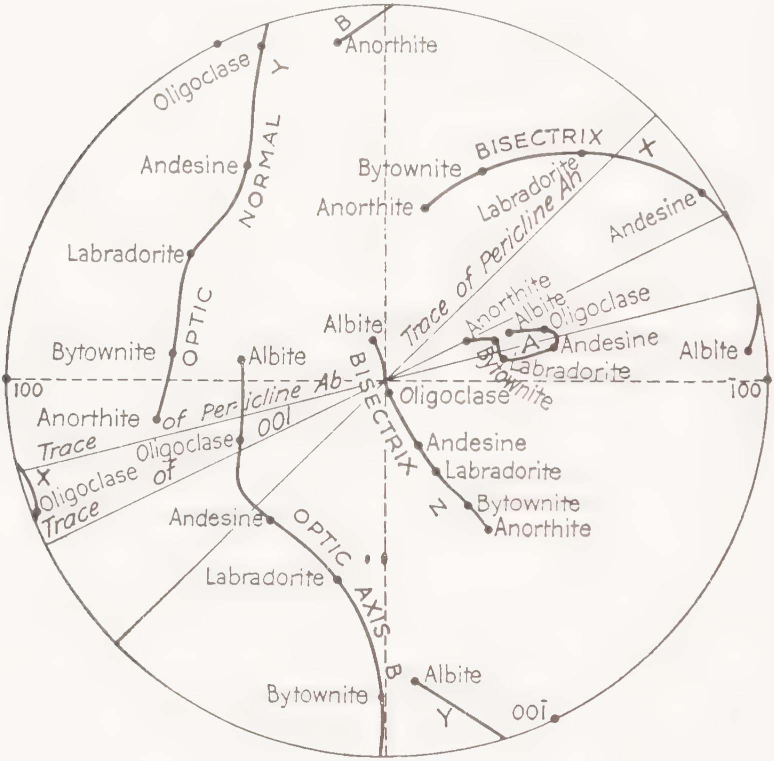

Fig. 229.—Stereographic projection of the optic elements in plagioclase on 010. (After Duparc and Reinhard.)

In plagioclase the position of the optic elements is varied. It is shown in Fig. 228 as projected on a plane normal to the axis *c*, in Fig. 229 as projected on 010, and in Fig. 230 as projected on a plane normal to the axis *a*. From albite to anorthite there is a gradual rotation of the optic plane in a direction anticlockwise about a line nearly parallel to the optic axis A, which is nearly normal to the plane $\bar{2}\bar{4}1$, the whole movement amounting to about 110°.

Optic Angle and Sign.—The optic angle is about 70° in orthoclase and about 80° in microcline, but it is only about 40° in anorthoclase and is still less in the high temperature form of orthoclase here called sanidine. In all potash feldspars the sign is negative.[33] In plagioclase the optic angle is 77° about Z in albite and increases to nearly 100° about Z (therefore negative) in oligoclase of composition $Ab_{75}An_{25}$, then decreases to about 75° in labradorite of composition $Ab_{45}An_{55}$, finally increasing again to more than 100° about Z in anorthite.

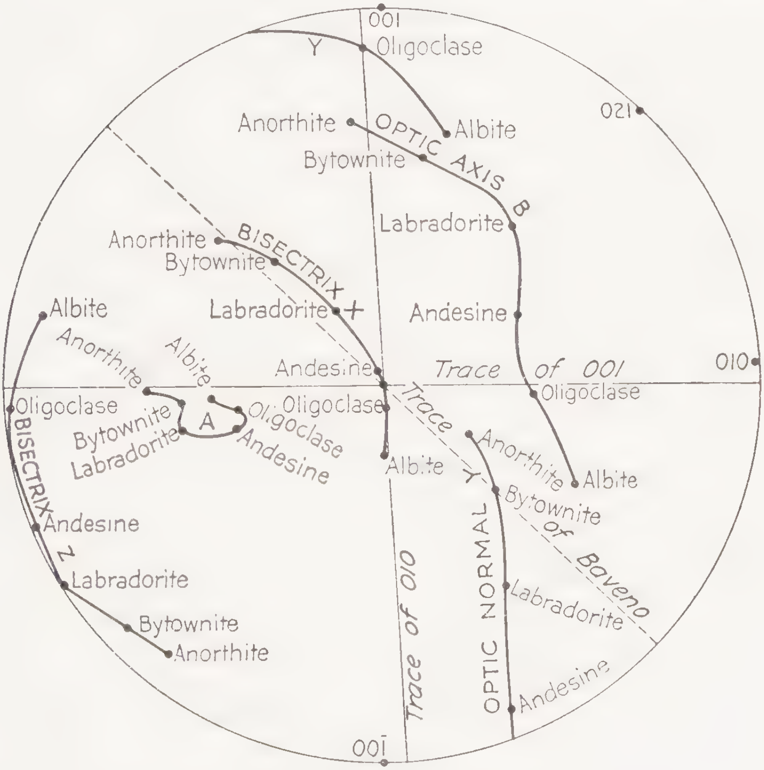

Fig. 230.—Stereographic projection of the optic elements in plagioclase on a plane normal to the axis *a*. (After Duparc and Reinhard.)

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[33] Positive varieties of orthoclase and of microcline have been reported, but if they occur they are certainly very rare.

These changes are shown in Fig. 205. The optic angle in plagioclase varies between 74° and 103° about Z, changing sign three times. The sign is positive in celsian, albite, andesine, labradorite, and some bytownite, and negative in other types.

OPTIC ANGLE, SIGN, DISPERSION AND DENSITY IN THE FELDSPARS

Name	2E	2V	Sign	Dispersion		Sp. Gr.
				About Bx_a	Of Bisectrix	
Celsian (Cn)	180° +	86.5	+			3.384
Hyalophane ($Or_{70}Cn_{30}$)....	155°	78.5°	−	$\rho > v$	....	2.818
Orthoclase (Or)...........	120° ±	69° ±	−	$\rho > v$	Distinct Horizontal	2.54
Sanidine (Or)............	0°–50°	Small	−	$\rho < v$	Distinct Inclined	2.54
Soda orthoclase (Or,Ab)...	120° ±	70° +	−		Horizontal	2.55
Anorthoclase (Ab,Or).....	45°–90°	32°–54°	−	$\rho > v$	Horizontal	2.58
Microcline (Or)...........	180° ±	83° ±	−	$\rho > v$	Horizontal	2.55
Soda microcline (Or,Ab)...	100° ±	60 ±	−	$\rho > v$	Horizontal	2.57
Albite ($Ab_{100}An_0$).........	125°	71°	+	$\rho < v$	Very weak Horizontal	2.61
Oligoclase ($Ab_{75}An_{25}$).....	180° +	82°	−	$\rho > v$	Horizontal and inclined	2.65
Andesine ($Ab_{55}An_{45}$)......	180° +	81°	+	$\rho > v$	Horizontal and inclined	2.67
Labradorite ($Ab_{45}An_{55}$)...	140°	74°	+	$\rho > v$	Crossed and inclined	2.69
Bytownite ($Ab_{25}An_{75}$).....	180° +	86°	−	$\rho < v$	Horizontal and inclined	2.72
Anorthite (Ab_0An_{100}).....	160°	77°	−	$\rho < v$	Horizontal and inclined	2.76

REFRINGENCE AND BIREFRINGENCE.—All the feldspars have low refringence, and birefringence between 0.003 and 0.013 (usually about 0.008), both properties being approximately the same as in quartz. The refringence is nearly the same as that of Canada balsam, which varies with the concentration, and may be changed by evaporation of water, but whose value is usually about 1.540, the variations being usually not beyond 1.53–1.55. However, balsam dissolved in xylol, as now frequently used, may have an index as low as 1.52. The substitute for balsam known as "Kollolith" has an index which varies between 1.52 and 1.534. Since the refringence and birefringence of feldspars vary with variations of composition, the facts are best presented graphically, as done in Figs. 205, 248 and 246-248. In tabular form they may be summarized as follows:

REFRINGENCE AND BIREFRINGENCE OF THE FELDSPARS

Name	Approx. Comp.	N_g	N_m	N_p	$N_g - N_m$	$N_m - N_p$	$N_g - N_p$
Celsian.	Cn	1.5941	1.5886	1.5835	0.0055	0.0051	0.0106
Hyalophane. . .	$Or_{70}Cn_{30}$	1.5469	1.5451	1.5419	0.0018	0.0032	0.0050
Orthoclase. . . .	Or	1.5260	1.5237	1.5180	0.0023	0.0047	0.0070
Microcline. . . .	Or	1.5296	1.5264	1.5224	0.0032	0.0040	0.0072
Anorthoclase. .	(Ab,Or)	1.5305	1.5294	1.5234	0.0011	0.0060	0.0071
Albite.	Ab	1.536	1.529	1.525	0.007	0.004	0.011
Oligoclase	$Ab_{80}An_{20}$	1.5465	1.5428	1.5385	0.0037	0.0043	0.008
Andesine	$Ab_{60}An_{40}$	1.5570	1.5533	1.5500	0.0037	0.0033	0.007
Labradorite. . .	$Ab_{50}An_{50}$	1.5622	1.5576	1.5547	0.0046	0.0029	0.0075
Bytownite. . . .	$Ab_{25}An_{75}$	1.5735	1.5693	1.5645	0.0042	0.0048	0.0090
Anorthite.	An	1.5885	1.5832	1.5755	0.0053	0.0077	0.0130
Quartz . . .		1.5534		1.5443			0.0091
Balsam.			1.54 ± 0.01 (with xylol 1.52-1.53)				
Kollolith . . .			1.52-1.534				

INVERSION.—The low temperature form of orthoclase, called adularia inverts to the high temperature form, called sanidine, at about 900° C. The reverse inversion does not take place in dry crystals. Orthoclase is supposed to be only metastable at ordinary temperatures, the stable form being microcline. Shearing stresses seem to favor inversion of orthoclase to microcline, but the relations are still uncertain. Microcline is stable to its melting point.

INCLUSIONS.—Feldspars may contain inclusions, either gaseous, liquid, or solid, which are occasionally regularly placed, but in general these are not at all characteristic. However, inclusions are sometimes found which are more or less characteristic of certain types of feldspar; they will be mentioned in the detailed descriptions.

ALTERATIONS.—Feldspars alter in many different ways which may be classified as follows, although the natural conditions leading to alterations are too complex to permit any simple classification, and the following tabulation is intended only as a general outline of the major factors involved.

- I. Alterations of the zone of katamorphism.
  - A. Chiefly in the belt of weathering.
    - 1. Change to kaolinite, pyrophyllite, halloysite, etc.
    - 2. Change to hydrargillite, quartz and calcite.
  - B. Chiefly in the belt of cementation.
    - 1. Change to zeolites.
    - 2. Change to prehnite.
    - 3. Change to glauconite.
    - 4. Changes of the belt of weathering, here subordinate.
- II. Alterations due to hot solutions.
  - A. Solutions acid.
    - 1. Change to tourmaline, topaz, etc.
  - B. Solutions alkaline.
    - 1. Change to sericite, kaolinite, hydrargillite, quartz with calcite, albite, adularia, chlorite, etc.
- III. Alterations of the zone of anamorphism.
    - 1. Change to quartz, calcite and epidote.
    - 2. Change to albite, zoisite, quartz and muscovite (saussuritization).
    - 3. Change to scapolite.
- IV. Alterations due to heat alone.

Kaolinite forms more frequently from acid rather than basic feldspars; it usually forms very small flakes which give the feldspar a cloudy appearance. Further development makes the original mineral opaque. This is believed to be the ordinary mode of origin of common clay, although the concentration in clay beds is accomplished in some cases by water sorting during transportation. Pyrophyllite is formed much less frequently by this method of rock decomposition. When the process of hydration goes still farther it may result in the formation of halloysite, montmorillonite, or other hydrous aluminum silicates.

Hydrargillite may be distinguished from the preceding alteration products by its distinctly oblique extinction in sections normal to the cleavage, and by common multiple twinning. It is found especially in basic igneous rocks, affecting particularly the microlitic feldspars or basalt. It is commonly accompanied by secondary quartz and calcite.

Zeolites may result from the alteration of feldspars, especially in basic rocks. The formation of zeolites seems in some cases to involve solution, more or less transportation, and deposition in amygdules. In some cases the change is indirect; dipyrite may form from the feldspar and in turn change to some zeolite. The formation of zeolite may begin in nephelite, or a related mineral, and later encroach on a feldspar.

The alteration of feldspar to prehnite resembles the change to zeolites, with which prehnite is often associated. Calcite and quartz may be formed simultaneously.

The alteration to glauconite is found in limestones, in which the clastic grains of orthoclase are sometimes impregnated with lamellæ of glauconite which gradually transform the whole grain to an aggregate of very fine green glauconite. This process is now in progress at the bottom of the ocean in some places. Glauconite of the Tertiary limestones is probably in part of the same origin, though the mineral is also produced in large amount through the agency of various kinds of organisms.

Alterations due to hot solutions are common, especially in association with igneous intrusions. Acid solutions, which may be gaseous or liquid, may change feldspars to tourmaline or topaz, or to alunite often with native sulphur. Large pure masses of kaolinite seem to have been produced in this way in Cornwall. Alkaline solutions produce effects not so easily recognized, but in some cases feldspars are corroded and then enlarged by a new growth of adularia or albite oriented on the old feldspar; the same or similar conditions may produce sericite, chlorite, quartz, calcite, hydrargillite, etc. Mica is especially common as an alteration of feldspar, particularly acid types. The mica is secondary and therefore may be called sericite; optically it is characterized usually by a small optic angle, and chemically by water easily expelled. It is sometimes accompanied by secondary hydrargillite, quartz and calcite; in pegmatite, quartz and albite may be accompanying secondary products.

The alteration of feldspar to a mass of quartz, calcite and epidote is common. Such alterations are nearly always accompanied or followed by the introduction of iron, chiefly as limonite.

Saussuritization is a process confined to regions where gabbros have suffered dynamic metamorphism. It may be accompanied by the development of a schistosity due to shearing and recrystallization. The plagioclase of the gabbro is transformed by the process into a mass (named "*saussurite*") of zoisite, epidote, new acid feldspar, quartz, actinolite, sometimes with garnet and rutile, more rarely with scapolite and calcite. The pyroxene of the gabbros is changed at the same time to green amphibole or to glaucophane.

The alteration of feldspar to scapolite has been studied in great detail in the rocks of the Pyrenees by Lacroix. The special feature of the process is that a single crystal of dipyrite may form from a large number of feldspar crystals, thus giving rise to a rock of much coarser texture than its parent. This alteration may be due to regional metamorphism in some cases, and to hot solutions in other cases. It is nearly always accompanied by the uralitization of the pyroxene.

Alterations due to heat alone result in the opening of feldspars along cleavage planes and fractures, and their partial fusion and recrystallization. This process often charges the feldspars with gaseous and vitreous inclusions. It also changes ordinary orthoclase to the high temperature type; it is considered possible that it changes microcline to orthoclase.

It is worthy of note that the same minerals are formed as alteration products under different conditions, outlined above. This is due to the fact that all the factors producing alteration are not stated in a simple classification.

Alteration of feldspar may be followed by regeneration of the same or, more commonly, a more acid type of feldspar. In this way feldspar grains or crystals are sometimes much enlarged. The new feldspar is fresh and glassy, while the old is more or less permeated with alteration products. The old feldspar may be high temperature orthoclase and the new low temperature orthoclase; the old may be calcosodic feldspar and the new pure albite, or even adularia. Such changes occur in all kinds of rocks.

Occurrence.—The feldspars are the most abundant and most widely distributed minerals of the earth's crust. They serve as the usual basis of classification of the igneous rocks; they are almost as abundant in the metamorphic rocks, and even in the sedimentary rocks they are not rare as residual clastic fragments, and are also known as regenerated crystals. They are a normal product of crystallization of all the common types of magmas; they are a common product of metamorphism, both contact and regional; finally, they are often formed in veins from hot solutions, and abundantly in some pegmatite dikes under aqueo-igneous conditions.

Diagnostics.—Feldspars are the most abundant colorless constituents of igneous and metamorphic rocks; they are distinguished from quartz by their biaxial character and by the presence of cleavages and twinning. They are also characterized by low refringence and weak (rarely moderate) birefringence. They alter readily, as already described.

There are many ways of distinguishing between the various types of feldspars; these are discussed below, with special reference to microscopic methods.

1. *Chemical analysis.*—Chemical quantitative analyses of pure material is sufficient to determine any feldspar, except that it does not distinguish between orthoclase and microcline (whether soda-bearing or not) nor between anorthoclase and microscopic feldspar intergrowths known as perthite. .

2. *Microchemical tests* for various bases (see Part I, page 40) are, in general, only qualitative, but may be very helpful in certain cases.

3. *Solubility.*—Anorthite and celsian dissolve readily in HCl, bytownite dissolves slowly; all other feldspars are insoluble.

4. *Specific gravity and hardness.*—The feldspars do not differ appreciably in hardness; in specific gravity they vary from 3.84 in celsian through 2.55 in orthoclase and 2.61 in albite to 2.76 in anorthite.

5. *Cleavage angle.* Monoclinic feldspars (celsian, hyalophane and orthoclase) may be distinguished from plagioclase by measuring the cleavage angle, which is 90° in the former and about 94° in the latter. The pseudomonoclinic feldspars (microcline and anorthoclase) cannot be distinguished from the monoclinic by such measures.

6. *Twinning.*—Monoclinic feldspars are easily distinguished from triclinic plagioclase by the fact that the former show only simple twinning, while the latter are commonly twinned in lamellæ so as to produce external striations on 001, and bands or stripes in thin sections.

7. *The optic angle* is small in sanidine and in anorthoclase; it is large (65°–90°) in all other kinds of feldspar.

8. *The optic sign* is positive in celsian, albite, andesine, labradorite and some bytownite and negative in other types of feldspar.

9. *Indices of refraction.*—The mean index of refraction varies from a maximum near 1.59 in celsian through a minimum of about 1.52 in orthoclase, and a value of about 1.53 in albite to about 1.58 + in anorthite. The indices in various directions can be compared by the methods of normal and inclined illumination (see Part I, pages

69–77) with the index (or indices) of any substance with which the feldspar is in contact. By using the data of Fig. 205 and page 293 the feldspar may be accurately identified in many cases. In this connection it should be remembered that N_o of quartz is very constant and available from every quartz grain, and, also, that the index of Canada balsam is not invariable, but ranges from 1.534 to 1.540 in good sections free from xylol (as a solvent of the balsam). In other sections the range is as great as 1.52 to 1.545.

The comparison of indices of refraction can be made much more useful by using mineral powders in various liquids of known index (instead of thin sections mounted in balsam), as described in Part I, pages 73–76. Since such powders of feldspars consist in large part of 001 and 010 cleavage plates, the indices in these plates are especially important; they have been worked out for plagioclase as shown by the curves in Fig. 231, prepared by Tsuboi.[34] This method of determining plagioclase can be made quite accurate by using a monochromator, drawing curves to represent the dispersion of various suitable immersion liquids over the curves of dispersion of plagioclase at the left of the figure, and varying the wave length of the light used until the index (preferably N'_p) of the feldspar equals the index of the liquid. Then it is only necessary to follow the feldspar dispersion curves

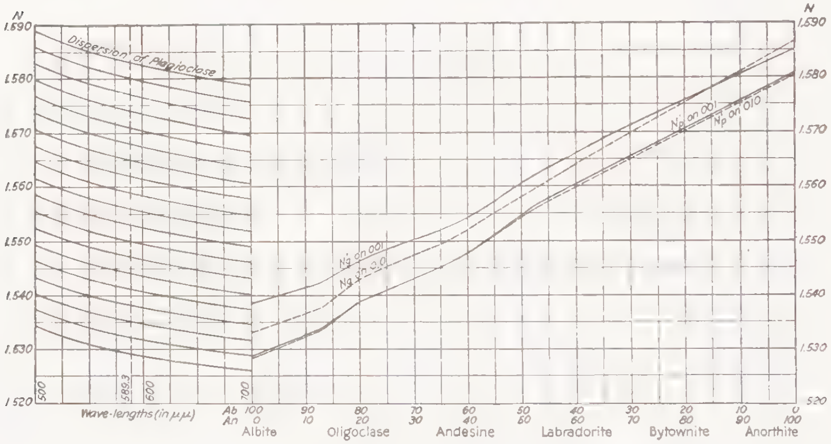

FIG. 231.—Indices of refraction on cleavage pieces in plagioclase. (After Tsuboi: *Mineral. Mag.*, XX, 1923, p. 108.)

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[34] *Mineral Mag.*, XX, 1923, p. 108.

to find the index of the feldspar for sodium light (589.3) which may be used on the index line of feldspar to obtain the composition of the latter. If the direction, to which the cleavage flake is parallel, is known, either index (N'_g or N'_p) of the flake may be used satisfactorily; if not, it is better to use N'_p since the N'_p lines are everywhere so close together that a point halfway between them gives the composition of the plagioclase with a maximum error of only 0.5 per cent.

10. *The interference figures from 001 cleavage flakes* show the following characters:

Celsian and anorthite show an optic axis at about 18° from the center of the field.

Sanidine shows an obtuse positive bisectrix Z at about 6° from the center of the field.

Labradorite and bytownite have no definite optic direction in the field.

Other feldspars show an optic normal at 4° to 20° from the center of the field.

11. *The interference figures from 010 cleavage flakes* show the following characters, which are quite useful if, as assumed in the following statements, it is possible to orient the flake with the vertical axis [35] running N–S, and the 001 cleavage extending NE–SW.

Celsian and sanidine show a centered optic normal.

Adularia and hyalophane show a centered obtuse positive bisectrix Z. In anorthoclase the obtuse positive bisectrix Z is about 3° from the center and in microcline it is about 12° from the center of the field.

The positive bisectrix Z is about 15° below the center and a little to the right in albite; very nearly at the center in oligoclase, about 20° from the center above and to the left in andesine; in labradorite and bytownite no definite optic directions are in field, and in anorthite an optic axis is near the edge of the field to the southwest.

Extinction angles are extremely useful in distinguishing between the various types of feldspar, but they are of no value unless the orientation of the crystal or grain can be learned in some way. Any orientation which can be recognized may serve for the measurement of extinction angles to be used in determining feldspars. The most important of these are described in the following paragraphs.

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[35] This may be recognized from crystal boundaries or from Carlsbad twinning since the twinning line, if visible in 010, is parallel with *c*, or, rarely, irregular.

12. *Extinction angles on 001 cleavage fragments* are tabulated on page 302 and included in Figs. 205 and 232. Only platy fragments of uniform thickness and therefore of uniform interference color should be used; further, the 010 cleavage, crystal face or twinning plane must be found, and the angle between it and the fast ray, X′, measured. Thin flakes are preferred to avoid the possibility of one crystal being superposed over another in the same flake. Extinction angles on 001 can not be used in thin sections because crystals cut in the required direction can not be recognized.

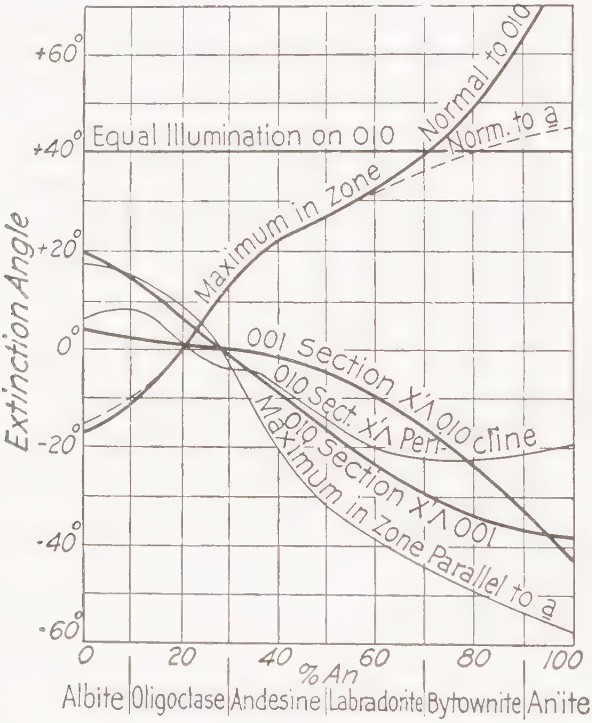


FIG. 232.—Extinction angles in crystallographically oriented sections or flakes of plagioclase. (After Duparc and Reinhard.)

13. *Extinction angles on 010 cleavage fragments* can be found in the table on page 302 and are included in Figs. 205 and 232. Cleavage fragments parallel to 010 are usually smaller and less abundant in a powder than those parallel to 001; they do not show albite twinning bands, but are likely to show two opposite parallel edges marking the 001 cleavage.

According to a rule proposed by Schuster extinction angles on 001 and 010 are considered positive if measured from the cleavage clockwise, and negative if measured anticlockwise, as illustrated in Fig. 233.

14. *Extinction angles in 010 sections.*—In thin sections, crystals cut parallel with 010 may be recognized by the absence of albite twinning (though pericline twinning may be present), by the presence of only one cleavage, and by the crystal form either in outline or in zonal growth with boundaries as shown in Figs. 234–236. In a section 0.02 mm. in thickness, if the section is only approximately parallel to 010 so that two albite lamellæ overlap through a width of not more than 0.3 mm., the section varies less than 4° from parallelism, and may be used by allowing a possible error of about ± 2° in the results. The 001 cleavage is usually quite distinct and nearly or quite normal to the section; it is seen best by darkening the field or lowering the condenser. Except in celsian, this cleavage is always near (0°–36°) the negative direction of extinction, and also near (0°–18°) the pericline twinning line. Such sections show a perfectly centered interference figure, if produced by monoclinic feldspar, and the bisectrix Z either in the field or nearer than X if produced by triclinic feldspar. Also, such sections may show Carlsbad B twinning, since this twinning has its composition face parallel to 100, and the basal cleavages in the two parts make an angle of 128° (or 52°) with each other. The extinction angles in the two parts of the Carlsbad twin are equal.

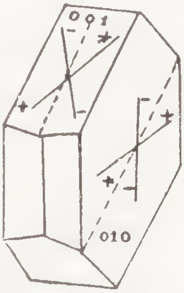
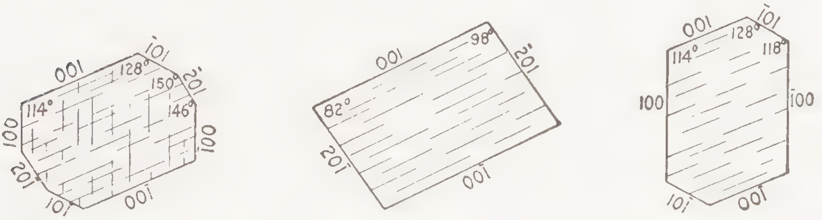


FIG. 233.—Schuster's rule for the sign of extinction angles in feldspars.



FIGS. 234–236.—Outlines of crystals of feldspar in sections parallel with 010.

EXTINCTION ANGLES OF THE FELDSPARS

Name	On 001	On 010	Angle measured from optic plane				Section ⊥ Y
			Section ⊥ X		Section ⊥ Z		
	X′∧010	X′∧001	Z∧010	Z∧001	X∧010	X∧001	X∧010
Celsian	0°	+28° (Z)	0°	90°	0°	90°	0°
Hyalophane	0°	− 5° to −4°	90°	0°		− 5° to −4°	0°
Adularia	0°	+ 5°	90°	0°	....	+ 5°	0°
Sanidine	0°	+ 5°	90°	0°	0°	90°	+ 5°
Soda orthoclase	0°	+11°	90°	0°	....	+11°	0°
Microline	+10° to +15°	+ 5°	88°	2°	....	+10°	15°
Anorthoclase	+ 2°	+4° to +10°	89°	1°	....	+9°±	+1° to + 4°
Albite, $Ab_{100}An_0$	+ 4°	+20°	+74°	+13°	+ 2°	+21°	+ 1°
Oligoclase, $Ab_{75}An_{25}$	+ 1°	+ 4°	−84°	− 9°	− 3°	+ 3°	0°
Andesine, $Ab_{55}An_{45}$	− 4°	−12°	−73°	−31°	−22°	−18°	− 8°
Labradorite, $Ab_{45}An_{55}$	− 7°	−18°	−63°	−40°	−28°	−30°	−15°
Bytownite, $Ab_{25}An_{75}$	−17°	−31°	−58°	−55°	−40°	−49°	−28°
Anorthite, Ab_0An_{100}	−40°	−38°	−59°	−73°	−62°	−64°	−41°

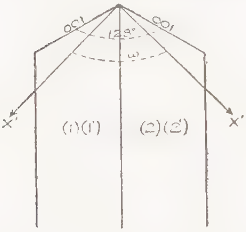


FIG. 237.—Carlsbad twinning and crystal outline in a section of feldspar parallel with 010.

In such twins the angle (ω) between the X′ extinction positions in the two parts of the twin, if the section is parallel with 010, are as follows (see Fig. 237):

Type	% An	ω	X′∧001
Albite	0	168°	+ 20°
Oligoclase	20	140°	+ 6°
Andesine	35	118°	− 5°
Labradorite	52	94°	−17°
Bytownite	73	66°	−31°
Anorthite	100	52°	−38°

In feldspar crystals showing zonal growth the section is parallel with 010 if the angle[36] from 001 (the basal cleavage) to the position of equal illumination of all the zones is + 40°. The zones are especially distinct in such sections, and since they follow crystal outlines they may be useful.

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[36] This angle is given as 37° by Michel Lévy and as 40.5° by Duparc and Reinhard.

When the position of the basal cleavage and that of some face of the vertical zone (as 110) can be determined, the sign of the extinction angle is given by the rule that positive angles are in the obtuse angle β and negative angles in the acute angle β. If basal cleavage and Carlsbad twinning are both visible, the rule may be applied, since the twinning line, if straight, may be taken as parallel with c.

15. *Extinction angles in sections normal to a* are tabulated on page 303 and shown in Fig. 232. Such sections are easily recognized by their nearly square outlines or by zonal growths with such outlines, and also by the fact that they are at right angles to both cleavages (and to the albite twinning) so that these lines are not displaced laterally when the focus is raised or lowered; in such sections albite twins show symmetrical extinctions and equal illumination at 0° and 45°. The sign of the extinction angle is given by Schuster's rule. Sections not exactly at right angles to a can be used by allowing a small margin of error, since the extinction angles do not change rapidly in this region.

EXTINCTION ANGLES OF THE FELDSPARS

Name	Zone ⊥ 010	Zone ‖ a	Section ⊥ a	Section ⊥ A		Section ⊥ B	
	Max. = Angle	Max. = Angle		Angle measured from optic plane			
	X′∧010	Microlites	X′∧010	to 010	to 001	to 010	to 001
Celsian	0°	+28°	0°	0°	90°	0°	90°
Hyalophane	0°	+5° to +24°	0°	90°	−2° to −10°±	90°	−2° to −10°±
Orthoclase	0°	+ 5°	0°	90°	+ 2°±	90°	+ 2°±
Anorthoclase	2°	+ 9°±	+ 1°?	90°	+ 4°±	90°	+ 4°±
Microcline	+19°	+16°	+ 4°	90°	+ 2°±	90°	+ 2°±
Albite ($Ab_{100}An_0$)	−20°	+17°	−15°	+66°	−22°	+65°	+ 7.5°
Oligoclase ($Ab_{75}An_{25}$)	+ 6°	+ 5°	+ 7°	−82°	+ 6°	−81°	+ 9°
Andesine ($Ab_{55}An_{45}$)	+25°	−27°	+25°	−56°	+25.5°	−59°	+16°
Labradorite ($Ab_{45}An_{55}$)	+30°	−38°	+32°	−43°	+41°	−61°	+ 1°
Bytownite ($Ab_{25}An_{75}$)	+42°	−47°	+40°	−31°±	+54°?	−61°±	+ 1°?
Anorthite (Ab_5An_{95})	+56°	−57°	+44°	−22°±	+63°?	−61°±	+4°?

16. *Extinction angles in the zone parallel to a* are given on page 303 and also in Fig. 232. A single measure is not sufficient, since it is necessary to find the maximum extinction angle of the zone. The microlites of volcanic rocks are elongated parallel to *a* and may be too small to show twinning; in such cases this method may be used satisfactorily (if the maximum angle attains 12°) by using the index of refraction to distinguish between albite and andesine.

17. *Extinction angles in the zone normal to 010* are tabulated on page 303 and included in Figs. 205 and 232. In this case a single measure is not sufficient, since the maximum extinction angle in the zone must be found; half a dozen measures usually suffice, however, to obtain a value close enough to the maximum. Sections normal to 010 can be recognized, if albite twinning is present, by the following characters: (1) The twinning line bisects the angle between extinction positions of two adjacent twinning bands; that is, the extinction angle measured from the twinning line (= 010 cleavage) in one band is equal to, but in contrary direction from, the extinction angle in the next adjacent twinning band. (2) Twinning lines and cleavage lines do not move laterally when the focus (high power) is raised or lowered through the thickness of the section. (3) The twinned parts show equal illumination eight times in a complete rotation, namely, four times when the twinning line is parallel with each cross hair and *also four times at 45°* from the cross hairs. In these positions the lamellæ appear to belong to a single crystal, being separated only by a very narrow dark line, sometimes almost invisible. This test is extremely delicate and easily applied. Sections varying up to 10° or 15° from the true zone may still be used by adopting the average value of the extinction angles. That is, if the extinction angles do not differ more than 2° or 3° (or, with large angles, more than 10 per cent) the average value is sufficiently accurate. The angle should be measured in all cases from the fast ray (X′) to the albite twinning line (or 010 cleavage). The sign of the extinction angle is nearly always unknown; therefore the method does not distinguish between albite and andesine, but they may be distinguished by the index of refraction method.

This method is somewhat tedious because the *maximum* angle of the zone must be obtained, but it is reliable and serviceable because of the readiness with which sections normal to 010 can be recognized, and also because there are decided differences in the maxima of the different feldspars. The chief objections to the method are due to (1) the possible existence of two or more feldspars in the same rock, and (2) the possible absence of the section showing the maximum equal extinction angle in any of the crystals of the random rock section. However, the second difficulty is not serious unless the section cuts only a few crystals of feldspar, and the obvious remedy is to secure more sections. The first difficulty is more serious and is only partly obviated by the fact that when two feldspars are present in one rock they *may* differ in transparency, or mode of distribution, or other evident characters.

18. *Extinction angles in albite-Carlsbad twins cut normal to 010.* In case any section normal to 010 is twinned both on the albite and the Carlsbad laws, a single section is sufficient to identify the feldspar, and it is unnecessary to hunt for the maximum equal extinction angle of the zone. Such crystals may be recognized by the fact that at the 45° position the albite twinning disappears and the crystal seems to be a simple Carlsbad twin, while at the 0° position both the albite and Carlsbad twinning disappear, except for fine dark lines due to overlapping of the albite twinning lamellæ. Such sections give equal extinction angles in the albite lamellæ in each part of the Carlsbad twin, thus giving two pairs of equal angles. In Fig. 205 the horizontal lines express the value of the small equal extinction angles, while the curves ("Albite-Carlsbad twinning") express the value of the larger equal extinction angles. The vertical lines give the percentage of anorthite. In using these curves there is no possible ambiguity except in cases in which both pairs of equal extinction angles are 16° or less; and, in such cases, if the two parts of the Carlsbad twin show practically no difference in birefringence at the 45° position the plagioclase is more acid than oligoclase (Ab_5An_1), and if a distinct difference appears (0.003 or more), the plagioclase is more basic than oligoclase. Sections inclined as much as 10° from the zone normal to 010 may be used with approximate accuracy by adopting the averages of the unequal extinction angles as equivalent to the equal angles that would be obtained if the orientation were correct.

19. *Extinction angles in zoned albite twins cut normal to 010.*—If a section normal to 010 shows zonal growth as well as albite twinning, a single section is sufficient to identify the feldspar by the aid of Fig. 238. It is necessary only to measure the smallest angle from 010 to a position of equal illumination of all the zones, find the corre-

sponding point on the diagram, and from that point follow the ordinate to a point on (or between) the extinction angle curves which represents the extinction angle ($X' \wedge 010$) in the given section; if the position of equal illumination and the extinction position are measured in the same direction from 010, the corresponding points on the diagram are on the same (right or left) half of the diagram; if not, they are

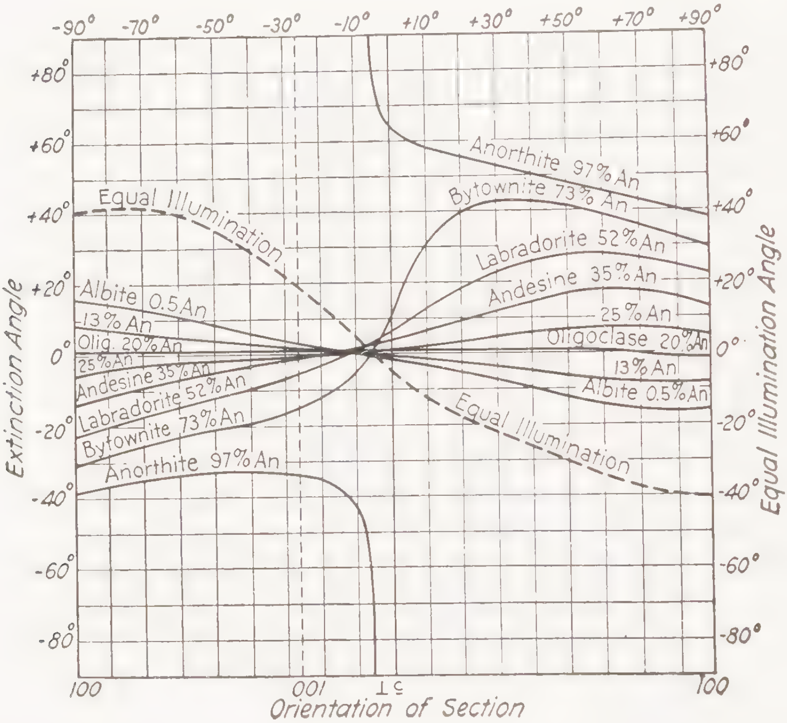

Fig. 238.—Extinction angles in sections of plagioclase normal to 010 with both albite twinning and zonal growths. (Modified from Duparc and Reinhard.)

on opposite sides of the diagram. Unfortunately, a given angle to a position of equal illumination can be found on either side of the diagram, so there are commonly two possible solutions; some other method must be used to enable one to choose correctly between these two solutions.

20. *Extinction angles in sections normal to an optic axis* are not often useful for three reasons: (1) it is often impossible to distinguish

between the two optic axes,[37] (2) such sections are nearly at extinction in all positions, and therefore the correct position of extinction is very difficult to recognize, and (3) extinction angles in this region vary very rapidly so that only sections very accurately oriented (with the optic axis exactly in the middle of the field) can be used. However, in spite of these difficulties such sections deserve attention, because they are easily recognized by their extremely weak birefringence, and also because the extinction position can be obtained by making the isogyre parallel with one cross hair. In a section normal to either optic axis an extinction angle, measured from the optic plane to 010, which is less than 45°, means that the feldspar is more basic than andesine, and an angle greater than 68° means that the feldspar is some kind of oligoclase. Extinction angles between 45° and 68° are indeterminate, but an angle of about 53° is distinctive of labradorite. Finally, sections normal to an optic axis are especially useful if they form part of a twin, since the extinction angles in the other part of such sections of twinned crystals are known (see page 309 and Figs. 239 and 240). In these crystals extinction angles are measured from the twinning line to the trace of the optic plane. If they are twinned, the extinction angles in other parts of the twin are measured from the vibration direction of the fast ray, X′. The sign of the extinction angle (given by Schuster's rule) is very rarely determinable in practise. In case the crystal concerned is twinned on the pericline law, the extinction angles, measured from the twinning line to the trace of the optic plane, are different; they are given for both parts of the twin on page 309. Extinction angles on various types of twinning are shown in Figs. 239 and 240.

21. *Extinction angles in sections normal to Y*, or parallel to the optic plane, are tabulated on pages 302 and 309, and included in the graphs (Figs. 205 and 241). Such sections are easily recognized by the fact that they show the highest interference color given by

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[37] But if both cleavage directions can be found the angle between them serves to distinguish A from B, except in oligoclase, by using the following data:

Angles between cleavages (001 ∧ 010) in sections normal to optic axes.

Section	$Ab_{100}An_0$	$Ab_{75}An_{25}$	$Ab_{55}An_{45}$	$Ab_{45}An_{55}$	$Ab_{25}An_{75}$	Ab_0An_{100}
⊥ A	88°	88°	81.5°	84°	85°	85°
⊥ B	57.5°	90°	75°	62°	62°?	64°?

Also, the optic plane turns perceptibly in succeeding zones (or zonal growth) in sections normal to A, while it does not turn (though B moves in a plane normal to the optic plane) in sections normal to B, according to Becke.

any crystal of the feldspar, and also (more accurately) by the fact that they give a " flash " interference figure. They give satisfactory results in the basic feldspars, but the extinction angles are not distinctive among the acid feldspars. The extinction angle should be

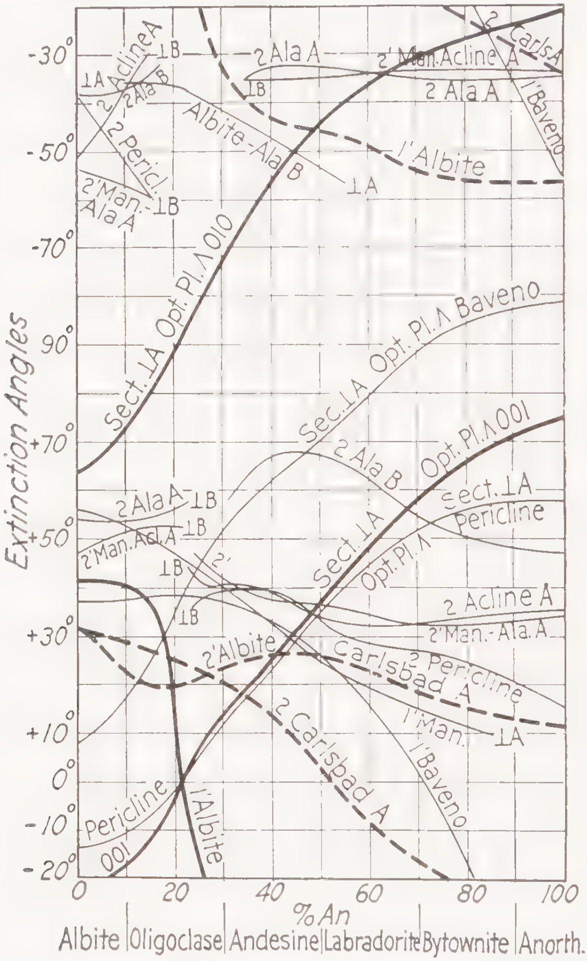

FIG. 239.—Extinction angles in sections of plagioclase normal to the optic axis A and in parts twinned therewith on various laws. (Modified from Duparc and Reinhard.)

measured from the fast ray (X) to the albite twinning, or 010 cleavage. In the uncommon case of pericline twinning without albite, the extinction angles from X′ to this twinning line are tabulated on page 309. For various types of twinning the extinction angles are also shown in Fig. 241.

EXTINCTION ANGLES NORMAL TO A, B AND Y IN PLAGIOCLASE [38]

Name	Section ⊥ A (1) Opt. Pl.∧010	(1′)	(2)	(2′)	Section ⊥ B (1) Opt. Pl.∧010	(1′)	(2)	(2′)	Section ⊥ Y (1) X∧010	(1′)
Albite ($Ab_{100}An_0$)	+ 66°	+ 37°	+ 30°	+ 28°	+ 65°	+ 40°	+ 45°	− 32°	+ 1°	
Oligoclase ($Ab_{80}An_{20}$) . .	90°	0°	+ 25°	+ 25°	90°	90°	− 35°	− 25°	+ 1°	
Oligoclase ($Ab_{75}An_{25}$) . .	− 82°	− 40°	+ 22°	+ 22°	− 81°	− 42°	− 17°	− 16°	0°	
Andesine ($Ab_{60}An_{40}$) . . .	− 63°	− 48°	+ 15°	+ 35°	− 59°	− 31°	− 6°	0°	− 3.5°	3°
Labradorite ($Ab_{50}An_{50}$)	− 47°	− 40°	+ 10°	+ 27°	− 57°	− 23°	+ 3°	+ 14°	− 13°	12°
Anorthite (Ab_0An_{100}) . . .	− 20°	− 53°	− 25°	+ 15°	− 62°	− 12°	+ 47°	− 56°	− 41°	38°
	Albite twin		Albite twin		Albite twin		Albite twin		Albite twin	
	Carlsbad twin				Carlsbad twin					

EXTINCTION ANGLES ON PERICLINE TWINNING IN PLAGIOCLASE

Name	Section ⊥ A (1)	(1′)	Section ⊥ B (1)	(1′)	Section ⊥ X (1)	(1′)	Section ⊥ Y (1)	(1′)	Section ⊥ Z (1)	(1′)
Albite ($Ab_{000}An_0$)	+ 5.5°	+ 41°	− 10.5°	− 35.5°	+ 77°	− 76°	− 13°	− 16.5°	− 3°	− 1°
Oligoclase (Ab_4An_1). . . .	− 4.5°	− 61°	0°	+ 30°	− 86.5°	+ 89.5°	……	……	− 3°	− 3.5°
Oligoclase (Ab_3An_1). . . .	− 10.5°	− 43.5°	+ 4°	+ 49.5°	− 75.5°	+ 85°	……	……	− 4.5°	− 4°
Andesine (Ab_5An_3). . . .	− 20°	− 35°	+ 12.5°	+ 42.5°	− 68.5°	+ 69°	− 17°	− 25°	− 6.5°	− 1.5°
Labradorite (Ab_1An_1) . .	− 25.5°	− 23.5°	+ 19.5°	+ 66°	− 57.5°	+ 57°	− 12°	− 34°	− 8°	+ 7.5°
Labradorite (Ab_3An_4) . .	− 38°	− 17°	+ 15.5°	+ 49.5°	− 49.5°	+ 42°	− 20°	− 68°	− 17.5°	+ 12°
Anorthite (Ab_0An_{100}) . .	− 57°	− 17°	− 35°	+ 13°	− 34.5°	+ 21°	− 24.5°	+ 76.5°	− 33.5°	+ 19.5°
	Pericline twin		Pericline twin		Pericline twin		Pericline twin		Pericline twin	

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[38] Columns A and B from revised data of F. Becke (*Tsch. Min. Pet. Mit.*, XXXV, 1921, p. 31); last two columns from G. Césaro (*Bull. Soc. Fr. Min.*, XXXIX, 1916, p. 57), who gives for bytownite ⊥ Y an angle of 30°, and in the part albite-twinned with it an angle of 28°.

22. *Extinction angles in sections normal to a bisectrix* furnish the best method of determining plagioclase feldspars, in the opinion of the writer. The chief objection to this method lies in the difficulty of recognizing the sections; but with experience their recognition is not difficult, since they are characterized by intermediate birefringence, and (more accurately) by showing a centered bisectrix interference figure. When found, the next step is to determine by means of one of the accessory plates whether the section is normal

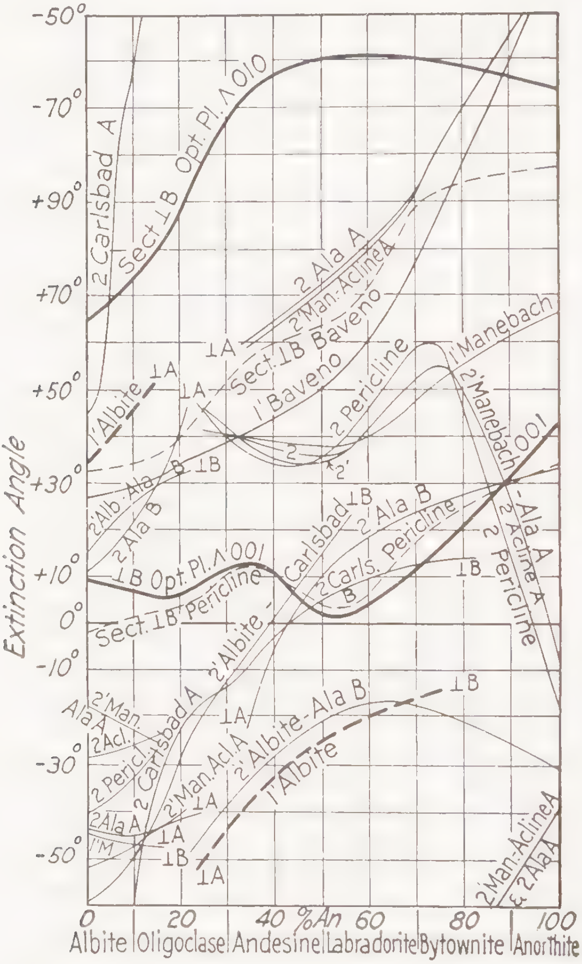

FIG. 240.—Extinction angles in sections of plagioclase normal to the optic axis B and in parts twinned therewith on various laws. (Modified from Duparc and Reinhard.)

to X or to Z (it is fortunately quite unnecessary to determine where the bisectrix is acute or obtuse). Then measure the extinction angle between the trace of the optic plane and a twinning line or cleavage. The data are tabulated on page 302. In sections normal to X the extinction angle is usually measured to albite twinning or 010 cleavage, and the proper curve of Fig. 205 or Fig. 242 then gives the percentage of anorthite present; but, especially in acid plagioclase, some sections normal to X do not show 010 cleavage nor albite twinning; in such cases the measurement may be made to 001 cleavage, if that is visible, and the result compared with the proper curve of the same figures. In sections normal to Z the extinction angle is usually measured from the trace of the optic plane to 001 in acid plagioclases, and to 010 in basic plagioclases, but if either happens to be invisible in any case the other may be used and the percentage of anorthite determined by reference to the proper curve of Figs. 205 or 243. Finally, in rare cases neither cleavage nor albite twinning can be seen, but a different type of twinning is visible. If

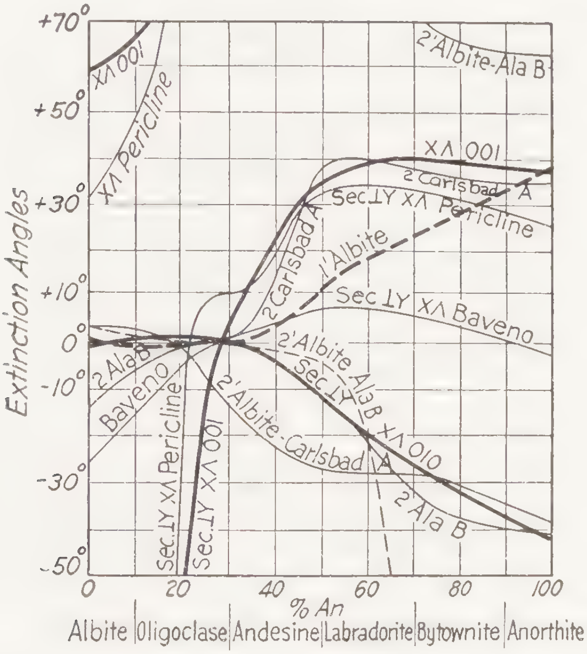

FIG. 241.—Extinction angles in sections of plagioclase normal to Y and in parts twinned therewith on various laws. (Modified from Duparc and Reinhard.)

this is lamellar it must be the pericline type, and the data on page 309 then give the determination required. Extinction angles to various types of twinning are given in Figs. 242 and 243.

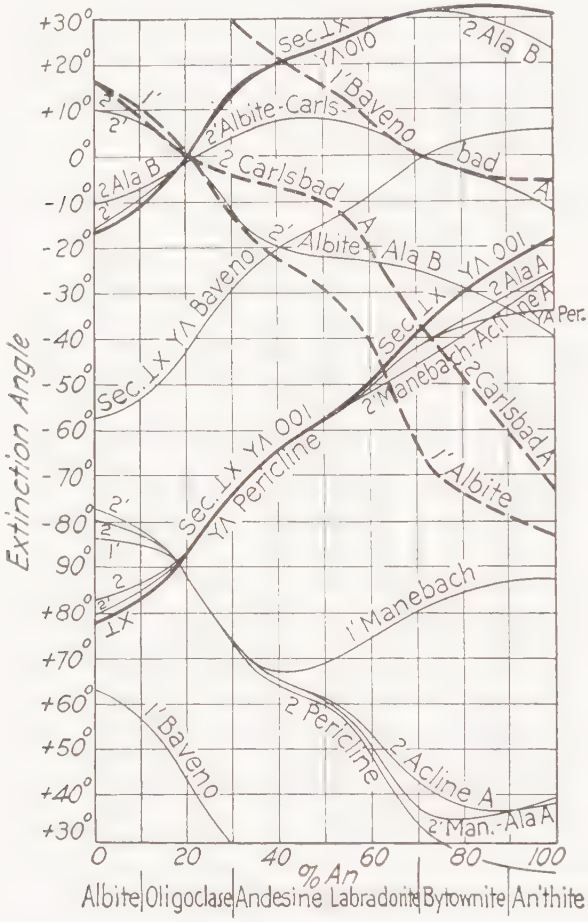

FIG. 242.—Extinction angles in sections of plagioclase normal to the bisectrix X and in parts twinned therewith on various laws. (Modified from Duparc and Rheinhard.)

CLASSIFICATION.—There are many unsettled questions in connection with the classification and relationships of the feldspars.

Potassium feldspar ($KAlSi_3O_8$) crystallizes at high temperatures to a monoclinic form first shown by Des Cloizeaux to be different optically from ordinary orthoclase and called by him abnormal orthoclase ("orthose déformé"). However, the glassy potassium feldspar of volcanic rocks has long been known as *sanidine*, and since this feldspar is almost invariably the high temperature type, it seems proper to adopt sanidine as the name of that crystal phase of potassium feldspar which is stable at high temperatures. In plutonic rocks potassium feldspar is found in a different crystal state known as ordinary orthoclase or *adularia*, which is probably formed at lower temperatures. Adularia changes to sanidine on heating to about 900° C., according to Merwin,[39] but the change is very sluggish in

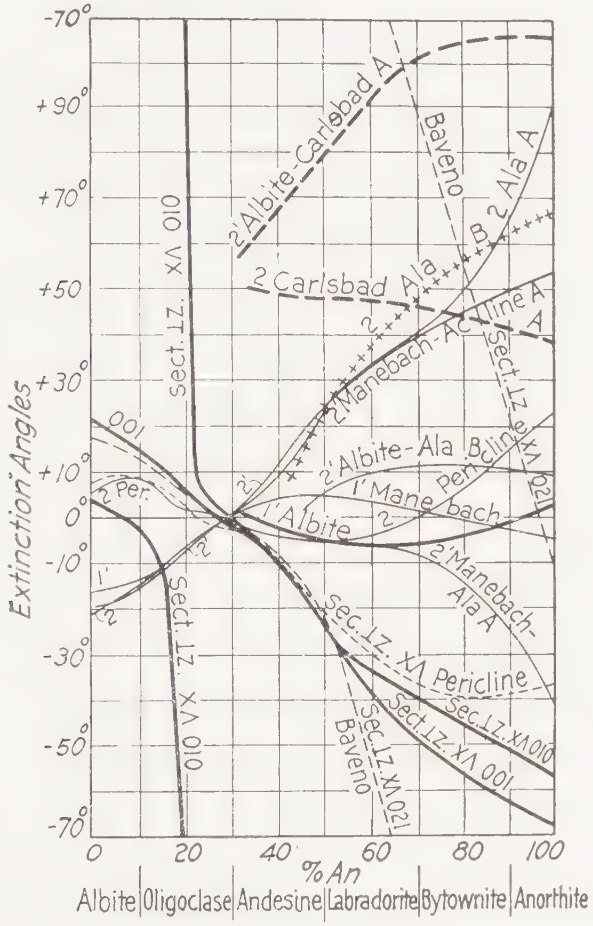

FIG. 243.—Extinction angles in sections of plagioclase normal to the bisectrix Z and in parts twinned therewith on various laws. (Modified from Duparc and Reinhard.)

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[39] *Jour. Wash. Acad. Sci.*, I, 1911, p. 59.

dry heat. The reverse change does not take place easily, but may occur with very slow cooling. According to Bücking,[40] pressure parallel to *b* causes the same changes in the optic angle of orthoclase as moderate increase of temperature. According to Alling,[41] shearing stresses at low temperature tend to cause orthoclase to invert to the triclinic form called *microcline*, but this needs further proof.

There has been much discussion concerning the relations between orthoclase and microcline. Many writers regard them as essentially identical, differing only in the coarseness of twinning, which is microscopically visible in microcline and considered to be present submicroscopically in orthoclase. Michel Lévy has shown that, within the limits of error, the extinction angles in 001 in adularia would be a necessary consequence of such submicroscopic twinning of microcline units. However, the most accurate measurements of specific gravity, optic axial angle, and refractive indices seem to indicate slight differences between orthoclase and microcline, and the observation of Merwin that orthoclase inverts at about 900° C., while microcline is stable to its melting point seems to show that the two are not identical.

Barium feldspar ($BaAl_2Si_2O_8$) is monoclinic and isomorphous with orthoclase; mixtures of barium and potash feldspars rich in potash are known as hyalophane, while the pure barium compound is called celsian. From its optical properties it is clear that hyalophane is a barium-bearing adularia; it is not certainly known whether celsian is related to adularia or to sanidine. If the relationship is to adularia the variations of physical properties with variations of composition must be about as shown in Fig. 244, but if the relationship is to sanidine a different diagram is needed.

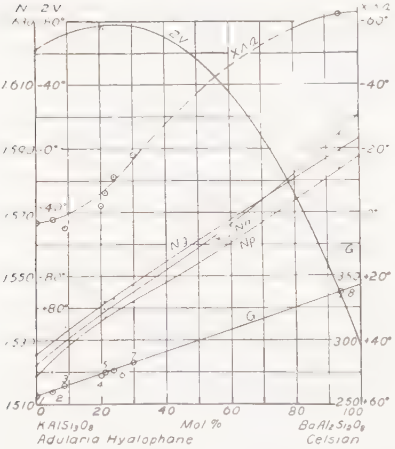

FIG. 244.—Variations in composition and optic properties in the adularia-celsian series.

The relations between the potassium and sodium feldspars are even more complicated and imperfectly known than those between orthoclase and celsian. The crystal form of the sodium feldspar, $NaAlSi_3O_8$, known in nature, is the triclinic albite. However, the albite molecule forms crystal solutions with all three crystal phases of potash feldspar, that is, with sanidine, adularia, and microcline. Merwin[39] has shown that albite inverts at about 900° C. to a different modification whose properties have not been determined; Mäkinen[42] has shown that the high temperature form of $NaAlSi_3O_8$ is miscible, probably in all proportions, with sanidine, and it is therefore probable that this high temperature form of $NaAlSi_3O_8$ is monoclinic; such a form has been named *barbierite* by Schaller.[43] Furthermore, nearly pure $NaAlSi_3O_8$ (with about 10 per cent $KAlSi_3O_8$) crystallizes in a pseudomonoclinic form called anorthoclase. The name *analbite*[44] has been suggested for this form of $NaAlSi_3O_8$. Accordingly, there are probably three crystal phases of $NaAlSi_3O_8$, as well as three of $KAlSi_3O_8$, and these are believed to belong to three series, namely:

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[40] *Zeit. Kryst.*, VII, p. 566.

[41] *Jour. Geol.*, XXIX, 1921, pp. 209, 275, and 292.

1. Sanidine-barbierite series, monoclinic and continuous; stable only at high temperature (above 900° C.); sanidine is metastable and barbierite unstable at ordinary temperature.
2. Adularia-albite series, monoclinic and triclinic, and discontinuous; stable at ordinary temperature.
3. Microcline-analbite series, triclinic, but discontinuous.

The discontinuity in the second series seems to extend from about $Or_{70}Ab_{30}$ to about $Or_{10}Ab_{90}$; that in the third series from about $Or_{80}Ab_{20}$ to about $Or_{40}Ab_{60}$. Members of this series from $Or_{40}Ab_{60}$ to $Or_{90}Ab_{10}$ are called anorthoclase.

The barbierite molecule is believed to separate on cooling from sanidine-barbierite mix-crystals to form aggregates of two feldspars, namely, adularia and albite, known as *perthite*. In some cases these aggregates are composed of microcline and albite, and they are then called *microclineperthite*. Sanidine-barbierite mix-crystals of composition between Or and about $Or_{70}Ab_{30}$ are metastable at ordinary temperature; those between $Or_{70}Ab_{30}$ and about $Or_{10}Ab_{90}$ are unstable and tend to form perthitic aggregates; pure barbierite changes to albite.

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[42] *Geol. För. Förh. Stockholm*, XXXIX, 1917, p. 121.

[43] *Bull. Soc. Fr. Min.*, XXXIII, 1910, p. 320; *Zeit. Kryst.*, L, 1911, p. 347; *Jour. Wash. Acad. Sci.*, I, 1911, p. 177; and *U. S. Geol. Surv.*, *Bull.* 509, 1912, p. 40.

[44] A. N. Winchell: *Jour. Geol.*, XXXIII, 1925, p. 714.

Some of these relationships are shown in Fig. 245 in which the break between the adularia-albite series and the microcline-analbite series is not intended to indicate any definite temperature, since pressure or shearing may be more important than temperature.

The probable relationships between optic properties and composition in the sanidine-barbierite series are shown in Fig. 246, which is unfortunately based on very scanty and unsatisfactory data.

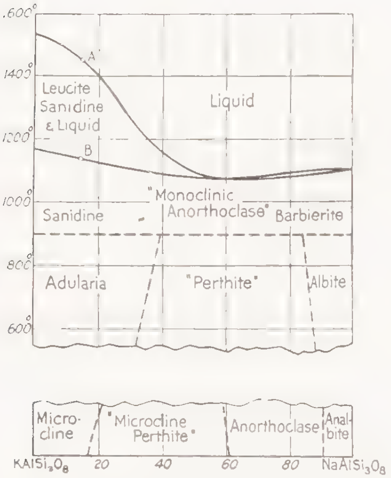

FIG. 245.—Stability relations in the potash-soda series of feldspars.

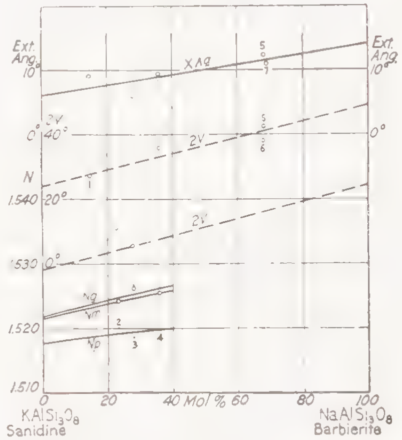

FIG. 246.—Variations in composition and optic properties in the sanidine-barbierite series.

The relationships between optic properties and composition in the adularia-albite series are shown in Fig. 247, which is based on better data than Fig. 246, but is, nevertheless, only an approximation.

The relationships between optic properties and composition in the microcline-analbite series are shown in Fig. 248, for which the data are not much better than for Fig. 246, though the properties of microcline are known fairly well.

The sodium and calcium feldspars are miscible in all proportions in triclinic crystals which are stable under a wide range of conditions, they form a continuous series, known as plagioclase, beginning with albite ($NaAlSi_3O_8$) and extending to anorthite ($CaAl_2Si_2O_8$). Intermediate mix-crystals have long been known as oligoclase, andesine, labradorite, or bytownite depending upon the ratio of albite to anorthite present, but there is no agreement as to the precise definitions of these names. The usages of various authorities are shown diagrammatically in Fig. 249, together with a modification proposed by the writer.

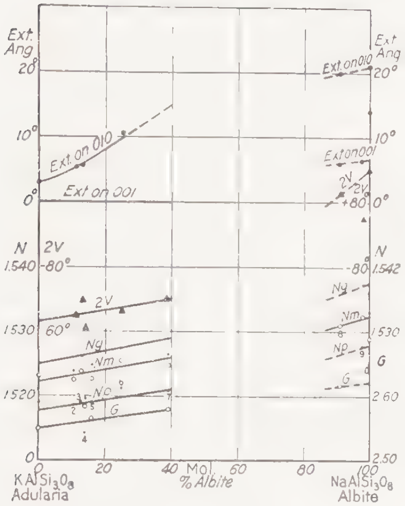

FIG. 247.—Variations in composition and optic properties in the adularia-albite series.

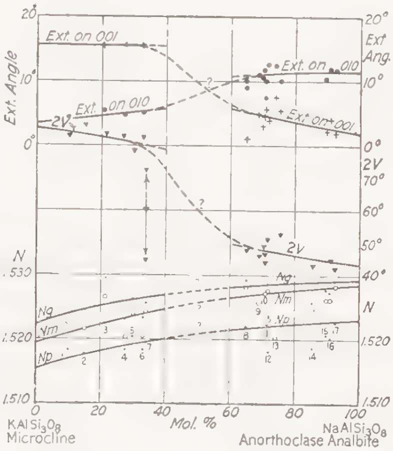

FIG. 248.—Variations in composition and optic properties in the microcline-analbite series.

Those who study minerals are accustomed to regard them as (elements or) compounds of definite chemical composition corresponding with some (more or less) simple chemical formula; therefore, even after the gradual acceptance of Tschermak's idea that albite and anorthite are miscible in all proportions in plagioclase, mineralogists have thought and written of triclinic feldspars in terms of various definite mixtures of the end compounds in simple ratios. This fact is responsible for much of the confusion regarding the classification of plagioclase. Such a practise is clearly not in harmony with the facts of nature (see Fig. 206), since it implies that the usual plagioclase crystal is composed of albite and anorthite in some simple ratio, whereas actual analyses show that simple ratios are mere accidents, and all possible ratios exist. Accordingly it seems better to use simple (decimal) ratios, not as characteristic of types, but as limits of types.

There has been a decided tendency during recent years to use compound names like oligoclase-albite to designate more exactly the kind of plagioclase found in various cases. This tendency began forty years ago in the writings of Schuster, and is well developed in the works of Lacroix,[45] who employs five such names. It is in the belief that it is desirable to adopt abbreviated forms of such names, and to give them definite meaning, that the plan presented in Fig. 249 has been developed.

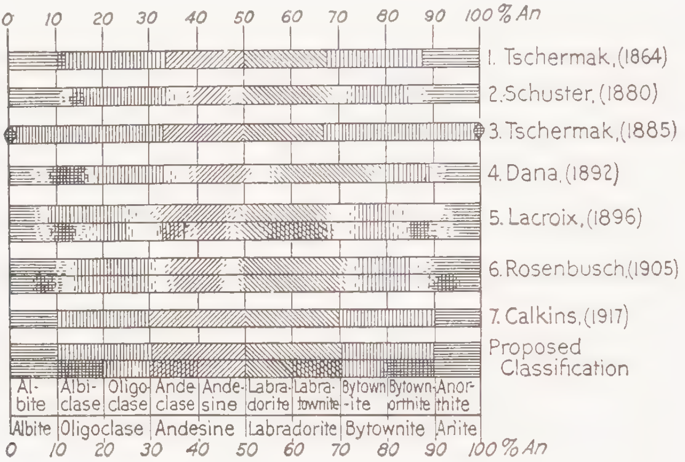

FIG. 249—Classification of plagioclase.

In tabular form the feldspars may then be classified [44] as follows:

MONOCLINIC FELDSPARS

Celsian		$BaAl_2Si_2O_8$ (= Cn)
Hyalophane		$mKAlSi_3O_8 + nBaAl_2Si_2O_8$
Orthoclase	Sanidine	$KAlSi_3O_8$ (= Or)
	Adularia	$KAlSi_3O_8$
Soda-orthoclase	Soda-sanidine	$(K,Na)AlSi_3O_8$
	Soda adularia	$(K,Na)AlSi_3O_8$
Barbierite		$NaAlSi_3O_8$ (hypothetical)

PSEUDOMONOCLINIC (TRICLINIC) FELDSPARS

Microcline	$KAlSi_3O_8$
Soda-microcline	$(K,Na)AlSi_3O_8$
Anorthoclase	$(Na,K)AlSi_3O_8$
Analbite	$NaAlSi_3O_8$ (very rare)

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[45] *Mineral. France*, II, 1896, p. 130.

PLAGIOCLASE (TRICLINIC) FELDSPARS

Albite [45a]		$(NaAlSi_3O_8 = Ab)$	$Ab_{100}An_0$ to $Ab_{90}An_{10}$
Oligoclase	Albiclase		$Ab_{90}An_{10}$ to $Ab_{80}An_{20}$
	Oligoclase		$Ab_{80}An_{20}$ to $Ab_{70}An_{30}$
Andesine	Andeclase		$Ab_{70}An_{30}$ to $Ab_{60}An_{40}$
	Andesine		$Ab_{60}An_{40}$ to $Ab_{50}An_{50}$
Labradorite	Labradorite		$Ab_{50}An_{50}$ to $Ab_{40}An_{60}$
	Labratownite		$Ab_{40}An_{60}$ to $Ab_{30}An_{70}$
Bytownite	Bytownite		$Ab_{30}An_{70}$ to $Ab_{20}An_{80}$
	Bytownorthite		$Ab_{20}An_{80}$ to $Ab_{10}An_{90}$
Anorthite [45a]		$(CaAl_2Si_2O_8 = An)$	$Ab_{10}An_{90}$ to Ab_0An_{100}

CELSIAN MONO. $a : b : c = 0.657 : 1 : 0.554$ $\beta = 115° 2'$ $BaAl_2Si_2O_8$

PHYS. CHAR.—Crystals short prismatic with 110 prominent as in adularia. Perfect 001, distinct 010, and less distinct 110 cleavages. Twinning according to Carlsbad, Baveno and Manebach laws. G. = 3.3–3.45. H. = 6. F. = 7. Soluble in HCl.

OPT. PROP.—The optic plane is parallel with 010; the acute bisectrix Z makes an angle of 28° with a, and X makes an angle of $+ 3°$ with c or $- 62°$ with a. In crystals about 94 per cent pure celsian Strandmark found $N_g = 1.5940$, $N_m = 1.5886$, $N_p = 1.5835$, $N_g - N_p = 0.0106$, $(+)\ 2V = 86° 22'$. In celsian from the same locality Tacconi[46] found $(+)\ 2V = 71° 58'$ and in celsian from Italy he found $(+)\ 2V = 83° 39'$ with no distinct dispersion. In artificial $BaAl_2Si_2O_8$:[47] $N_g = 1.600$, $N_m = 1.593$, $N_p = 1.587$, $N_g - N_p = 0.013$. If celsian corresponds with adularia rather than sanidine, as seems very probable, the relations must be about as shown in Fig. 244.

Colorless or yellow. Luster vitreous. Colorless in section.

INVER.—$BaAl_2Si_2O_8$ crystallizes at low temperature as hexagonal plates of uniaxial positive character according to Ginsberg;[48] Eskola[47] found no such forms.

OCCUR.—In igneous contact zones with garnet, schefferite, etc. Rare.

DIAG.—Celsian differs from orthoclase and hyalophane in optic sign, large extinction angle in sections or cleavage fragments parallel to 010, higher specific gravity and ready solubility.

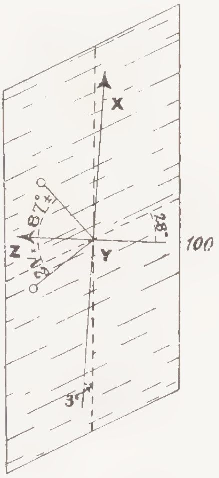

FIG. 250.—Optic orientation of celsian.

HYALOPHANE MONO. $a : b : c = 0.658 : 1 : 0.551$ $\beta = 115° 34'$ $Cn_{40}Or_{60}$ to $Cn_{10}Or_{90}$

PHYS. CHAR.—Crystals short prismatic with 110 prominent as in adularia. Perfect 001 and distinct 010 cleavages. Baveno twinning observed. H. = 6. G. = 2.6 to 2.8. F. = 6. Insoluble in acids.

[45a] Johannsen has recently proposed (*Jour. Geol.*, XXXIV 1926, p. 840) to use the terms *sodaclase* and *calciclase* for the two end-members of the plagioclase series, reserving the names albite and anorthite to designate the pure molecules; albite and anorthite would then be *minals* in the sense of Alling (*Jour. Geol.*, XXXIV, 1926, p. 591).

[46] *Zeit. Kryst.*, XLIII, 1905, p. 424; see also LIV, 1914, p. 388.

[47] *Am. Jour. Sci.*, CCIV, 1922, p. 331.

[48] *Min. Abst.*, II, 1923, p. 153.

OPT. PROP.—The optic plane is normal to 010; the extinction angle in 010 ($X \wedge a$) varies from about 0° to about − 25° with the basal cleavage (see Fig. 251). Distinct horizontal dispersion with $\rho > v$, weak. The properties vary with tenor of celsian, as follows (data from the graph, Fig. 244):

	$Or_{90}Cn_{10}$	$Or_{80}Cn_{20}$	$Or_{70}Cn_{30}$
(−) 2V =	74°	76°	78°
N_g =	1.534	1.541	1.547
N_m =	1.531	1.538	1.545
N_p =	1.523	1.535	1.542
$N_g - N_p$ =	0.006	0.006	0.005
$X \wedge a$ =	+ 2°	− 5°	− 16°
G. =	2.65	2.73	2.82

Colorless, white, greenish, pink. Colorless in section.

OCCUR.—In dolomite in manganese mines in Sweden, etc., apparently as a contact mineral.

DIAG.—Differs from orthoclase in extinction angle on 010, and also in specific gravity and presence of barium.

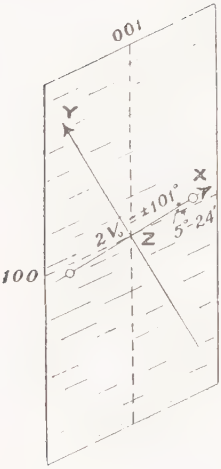

FIG. 251.—Optic orientation of hyalophane.

ORTHOCLASE MONO. $a : b : c = 0.6586 : 1 : 0.5559$ $KAlSi_3O_8$
$\beta = 116° 3'$

COMP.—Orthoclase of nature is practically never composed of the pure substance $KAlSi_3O_8$, but usually contains about 20 per cent of $NaAlSi_3O_8$ besides very small amounts of other molecules such as $CaAl_2Si_2O_8$, $RbAlSi_3O_8$, etc.

PHYS. CHAR.—Crystals of *adularia* short prismatic with 110 promiment, terminated by 001 and $\bar{1}01$. Crystals of *sanidine* often tabular parallel to 010, or elongated parallel to *a* with 001 and 010 prominent. Carlsbad twinning frequent; Baveno and Manebach uncommon. Perfect 001 and distinct 010 cleavages. Parting or poor cleavage parallel to $1\bar{1}0$ and 100. Fusion of pure $KAlSi_3O_8$ with formation of leucite[49] begins at 1170° C.; fusion is complete at 1530° C. (pure), and about 1450° C. (natural). H. = 6. G. = 2.56 (adularia), 2.57–2.58 (sanidine). Insoluble in acid.

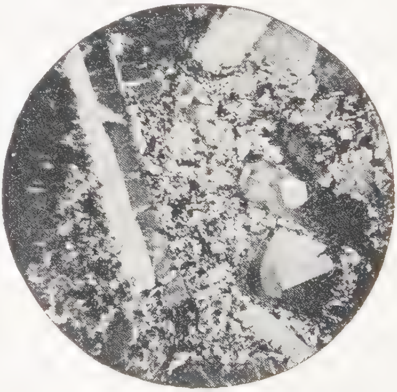

FIG. 252.—Photomicrograph of orthoclase in thin section showing Carlsbad and Baveno twins.

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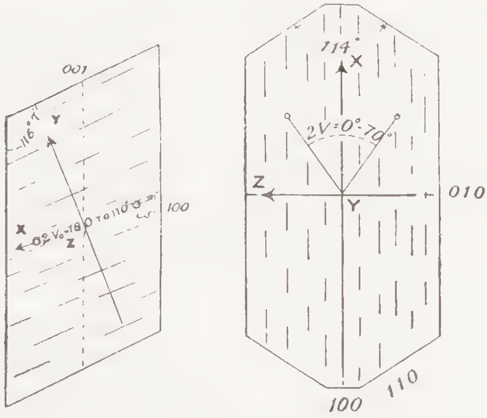
[49] G. W. Morey and N. L. Bowen: *Am. Jour. Sci.*, CCIV, 1922, p. 1.

OPT. PROP.—In adularia the optic plane and obtuse bisectrix Z are normal to 010, and the acute bisectrix X makes an angle of about 5° (to 8°) with *a* (the basal cleavage trace) in 010. Distinct horizontal dispersion with $\rho > v$. Optic sign negative.

$$(-)\ 2V = 70° \pm.$$

$$N_g = 1.525,\ N_m = 1.523,\ N_p = 1.519,\ N_g - N_p = 0.006.$$

When adularia is heated the optic angle decreases steadily, becoming 0° at 600° to 800° C., and then opening out in 010 at right angles to the previous position. At about 900° C., according to Merwin,[39] the mineral inverts to the high temperature form called sanidine.



FIGS. 253-254.—Optic orientation of adularia.

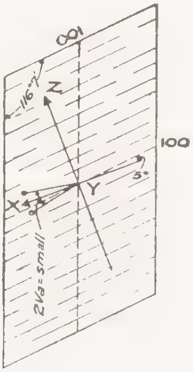


FIG. 255.—Optic orientation of sanidine.

If the temperature does not reach 600° C. the change is reversed on cooling and the final condition is about the same as at first. However, if the temperature passes 600° C., the change is not easily reversed, and the condition obtained by heating may remain with little change upon cooling. In this way the optic angle in orthoclase may be changed to almost any value (less than 70°) in the plane normal to 010, and from 0° to about 20° in 010. Natural orthoclase shows a similar variation in the size of the optic angle.

When orthoclase crystallizes at high temperature (or is heated above the inversion temperature) sanidine is produced, and upon cooling the substance does not change to adularia, at least under the usual natural conditions. In sanidine the optic angle is small to very small; the optic plane may be normal to 010, or parallel thereto, or normal to 010 in red light and parallel thereto in blue light. If the optic plane is parallel to 010, the dispersion is inclined (weak) with $\rho > v$.

$$(-)\ 2V = \text{small},$$

$$N_g = 1.5240,\ N_m = 1.5239,\ N_p = 1.5170,\ N_g - N_p = 0.007.$$

Ordinary orthoclase in cleavage (001 or 010) pieces has $N'_g - N'_p = 0.005 \pm$.

Ordinary orthoclase (both adularia and sanidine) contains up to 30 per cent $NaAlSi_3O_8$; crystals containing more than 30 per cent albite are stable only at high temperatures, but they are not rare as metastable substances at ordinary temperatures. Such feldspars are called soda-orthoclase (soda-adularia or soda-sanidine). The effects of the albite molecule upon the optic properties of adularia are shown in Fig. 247, and the effects upon sanidine are shown in Fig. 246, as inferred from very inadequate data. Soda-adularia has an extinction angle ($X \wedge a$) of 8° to 12° in 010. The monoclinic form of $NaAlSi_3O_8$, known only in crystal solution in orthoclase, has been named *barbierite*.

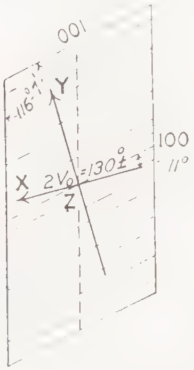


FIG. 256.—Optic orientation of soda-adularia.

Isorthoclase[50] is the name given to a rare variety of orthoclase said to be optically positive with a small optic angle, otherwise just like adularia.

Orthoclase is colorless, white, pink, red, yellow, gray, green; the luster is vitreous. Colorless in thin section.

INVER.—Adularia inverts to sanidine at about 900° C.

ALTER.—Orthoclase alters rather easily to kaolinite or to sericite. The change occurs both under weathering and hydrothermal conditions. Quartz often forms at the same time. Much more rarely the alteration is to a zeolite, or chlorite, or, under exceptional conditions, to glauconite, alunite or tourmaline.

OCCUR.—Orthoclase is very abundant in acid igneous rocks and common in igneous rocks of intermediate acidity; it is frequently found in contact zones and other metamorphic rocks; it is not rare in clastic rocks. Adularia found in veins is sometimes called *valencianite*. Regular intergrowths of orthoclase (or microcline) and albite, called *perthite*, are believed to be due to a secondary (" unmixing ") process by which a homogeneous crystal separates (without fusion or solution) into unlike parts as a result of instability induced by cooling.

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[50] L. Duparc: *Comp. Rend.*, CXXXVIII, 1904, p. 714.

DIAG.—Of all the feldspars sanidine has the smallest optic angle, and, except for anorthoclase, adularia is next smallest. Orthoclase (and microcline) have the lowest specific gravity found in the feldspars, and also the lowest refringence. Being monoclinic, orthoclase has no multiple twinning and the cleavage angle is exactly 90°.

MICROCLINE TRICLINIC $a : b : c = 0.6495 : 1 : 0.5546$ $KAlSi_3O_8$
$\alpha = 90° 7'$ $\beta = 115° 50'$ $\gamma = 89° 55'$

COMP.—Natural microcline is practically never composed solely of $KAlSi_3O_8$, but usually contains about 20 per cent of $NaAlSi_3O_8$, besides very small amounts of other molecules, such as $CaAl_2Si_2O_8$, etc.

PHYS. CHAR.—Crystals of microcline are very similar to those of orthoclase. Simple twinning according to the Carlsbad, Baveno and Manebach laws, and fine microscopic lamellar twinning according to the albite and microcline laws. The composition face of the microcline twinning makes an angle of + 99° in 010 with 001. Microcline has perfect 001 and distinct 010 cleavages, with poor cleavages or parting parallel to 110, or, rarely, $1\bar{1}0$. H. = 6. G. = 2.55. Fusion of pure $KAlSi_3O_8$ with formation of leucite[49] begins at 1170° C.; fusion is complete at 1530° C. (pure), and about 1450° C. (natural). Insoluble in acid.

OPT. PROP.—The optic plane and obtuse bisectrix Z are nearly normal to 010; the negative acute bisectrix makes an angle of + 5° in 010 with 001 (cleavage). The extinction angle in 001 is about + 15° from the 010 cleavage. The extinction angle referred to the trace of the optic plane in a section normal to X is 88° and in a section normal to Z is + 10°. The optic angle is large, showing notable horizontal dispersion with $\rho > v$.

$$(-)\ 2V = 83° \pm.$$

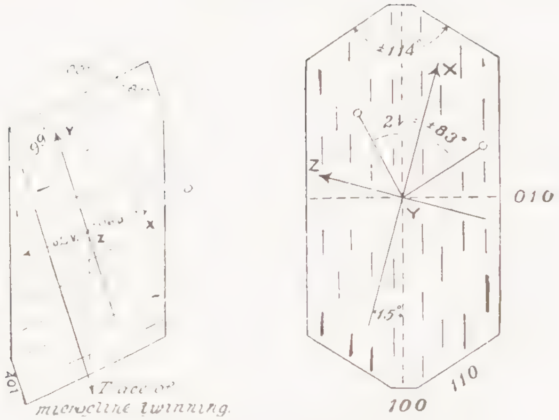
$$N_g = 1.525,\ N_m = 1.522,\ N_p = 1.518,\ N_g - N_p = 0.007.$$

Isomicrocline[51] is the name given to a rare variety which is said to be optically positive, though otherwise like normal microcline.

INVER.—Microcline is stable to its melting point, according to Merwin,[39] but inverts to orthoclase at 1000° + after 500–700 hours, according to Dittler and Köhler.[52]

[51] W. Luczizky: *Tsch. Min. Pet. Mit.*, XXIV, 1905, p. 347.

[52] *Tsch. Min. Pet. Mit.*, XXXVIII, 1926, p. 229.



FIGS. 257–258.—Optic orientation of microcline

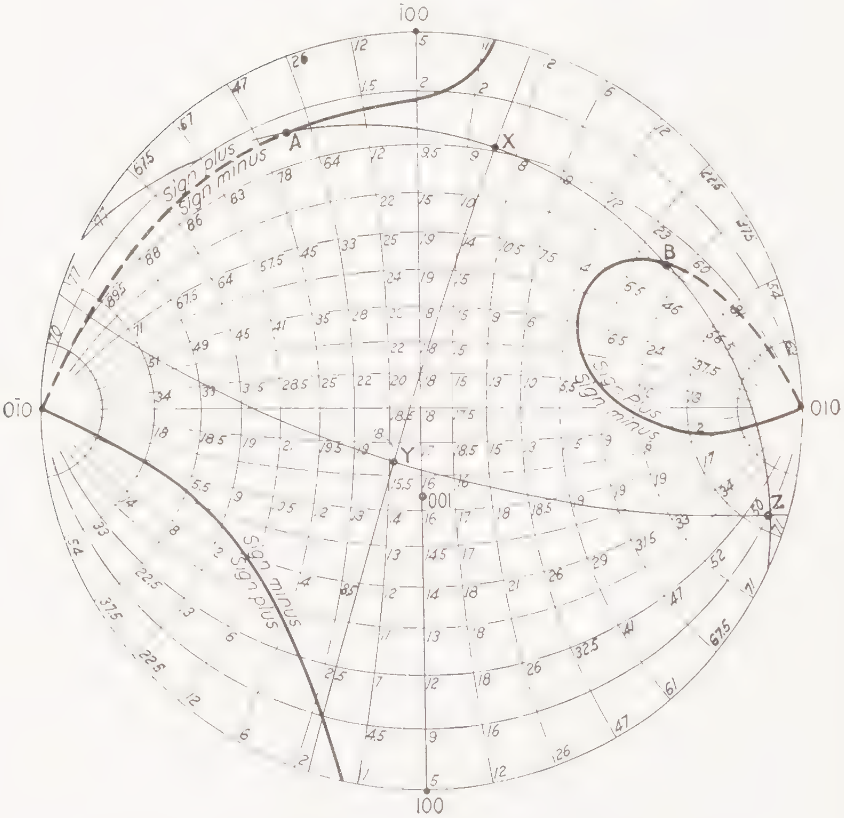


FIG. 259.—Stereographic projection showing extinction angles of microcline. (Modified from Rosenbusch-Wülfing: *Mikro. Phys.*, I, 2, 1905.)

ALTER.—The alteration of microcline to sericite, albite and quartz is rather common; microcline alters as easily and in the same way as orthoclase.

OCCUR.—Entirely similar to orthoclase, but especially common in pegmatite; common in shear zones, according to Alling.[41] Regular intergrowths with albite are similar in type and origin to those of orthoclase (see Fig. 261).

DIAG.—Microcline is characterized by the quadrille structure due to two sets of microscopic lamellar twinning, which are nearly at right angles. Lamellar twinning is not found in monoclinic feldspars. One set of such twinning is extremely common and two sets are not rare in plagioclase feldspar, but in the latter, one set (pericline) makes a small angle with 001 and is therefore invisible in sections or cleavage pieces parallel with 001, while in microcline the corresponding twinning is nearly normal to 001 and therefore distinct in sections or cleavage fragments parallel with the basal cleavage. Furthermore, the twinning of microcline wedges out in both directions, while that of plagioclase is more continuous and tends to end abruptly against another twinning band. Microcline devoid of multiple twinning is quite rare, but not unknown.

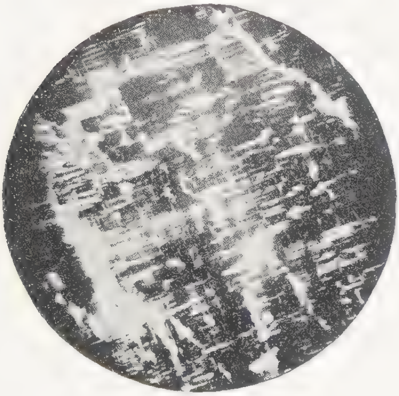


FIG. 260.—Photomicrograph of microcline in thin section, with some plagioclase. ×50.

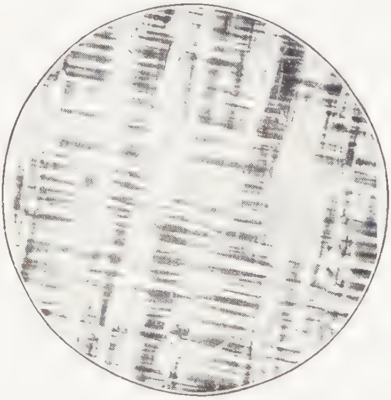


FIG. 261.—Photomicrograph of microcline-perthite in thin section. (Taken by H. L. Alling: see *Jour. Geol.*, XXIX, 1921, p. 193.)

ANALBITE TRICLINIC $NaAlSi_3O_8$

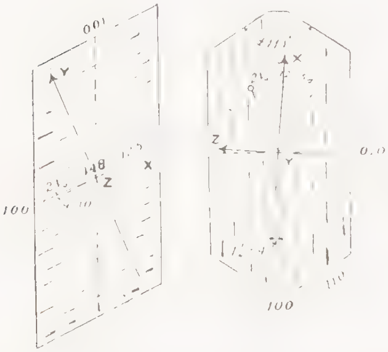
ANORTHOCLASE TRICLINIC $a : b : c = 0.6466 : 1 : 0.5522$ $(Na,K)AlSi_3O_8$

$\alpha = 90.5° \quad \beta = 116° 18' \quad \gamma = 90° \pm$

COMP.—Chemically anorthoclase is much nearer to albite than it is to orthoclase; the name is due to the fact that it is microscopically much like, but distinguishable from, orthoclase. If it contains less than 10 molecular per cent of $KAlSi_3O_8$ the name *analbite* has been suggested.[44] In case the twinning is well developed it is even more like microcline in thin section. Small tenors of other molecules, especially $CaAl_2Si_2O_8$, are common.

Phys. Char.—Crystals similar to those of orthoclase with 001, 010, 110, $1\bar{1}0$, $\bar{2}01$, etc. Prismatic or tabular parallel to 010. In some rocks (" rhomb porphyries ") crystals have only the faces 110, $1\bar{1}0$ and $\bar{2}01$. Twinning on the Carlsbad, Baveno, and Manebach laws; Carlsbad twins of the rhomb porphyries have 100 as the composition face. The characteristic twinning of anorthoclase is the combination of the albite and microcline lamellar types, differing only from microcline in the extreme narrowness of the albite bands. The composition face of the microcline twinning in anorthoclase makes an angle of − 75° to − 78° with 001 in 010. Twinning on an axis normal to $\bar{2}01$ is often also present. Anorthoclase free of multiple twinning is rare. Perfect 001 and good 010 cleavages. H. = 6. G. = 2.56–2.6. F. = 5. Insoluble in acid.

Opt. Prop.—The optic plane is nearly normal to 010, and the negative acute bisectrix, X, makes an angle of + 6° to + 12° with *a* in 010. The extinction angle in 001 is + 1° to + 6°, usually 1°–3°, while the extinction angle referred to the optic plane in sections normal to X is 80° to 89°, and in sections normal to Z is about 9°. Distinct horizontal dispersion.



Figs. 262, 263. Optic orientation of anorthoclase.

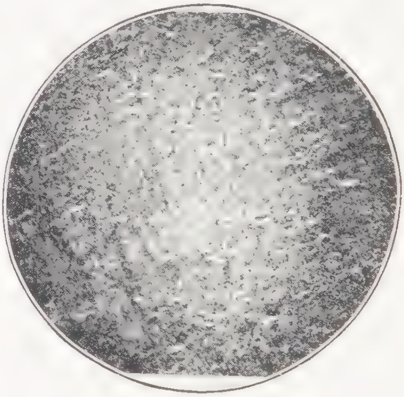


Fig. 264.—Photomicrograph of anorthoclase. (Taken by H. L. Alling—see *Jour. Geol.*, XXIX, 1921, p. 193. ×25.)

$(-)\ 2V = 42°$ to $54°$, $\rho > v$, $N_g = 1.529$, $N_m = 1.528$, $N_p = 1.523$, $N_g - N_p = 0.006$.

Colorless, or tinted; colorless in section. Internal reflections (" moonstone ") rare.

Inver.—Anorthoclase is stable to its melting point according to Merwin.[39]

Alter.—The methods and products of alteration are similar to those of albite.

Occur.—Found only in volcanic rocks rich in soda; often intergrown with sanidine.

Diag.—The quadrille structure due to two sets of lamellar twinning is nearly always present, and is composed of bands which are extremely narrow even as seen microscopically. The extinction angle in 001 (about 2°) is much smaller than in microcline (15°), the maximum equal extinction angle in the zone normal to 010 is 1° to 2°, and the optic angle is the smallest found in the feldspar group (except for sanidine).

PLAGIOCLASE TRICLINIC $a:b:c = 0.635:1:0.554$ $\left\{\begin{array}{c} NaAlSi_3O_8 \\ \text{to} \\ CaAl_2Si_2O_8 \end{array}\right.$

$\alpha = 93^\circ\ 5'$ to $94^\circ\ 31'$ $\beta = 115^\circ\ 54'$ to $116^\circ\ 38'$ $\gamma = 87^\circ\ 1'$ to $91^\circ\ 34'$

COMP.—A continuous series is known from pure albite ($NaAlSi_3O_8$ = Ab) to pure anorthite ($CaAl_2Si_2O_8$ = An); in nature a small tenor of orthoclase ($KAlSi_3O_8$ = Or) is nearly always present in plagioclase, as well as still less of other molecules.

PHYS. CHAR.—Crystals are commonly tabular parallel to 010, and sometimes elongated parallel to *a*; in "rhomb porphyries" and rarely in other rocks the elongation is parallel to *c* with prismatic form, the only faces being 110, $1\bar{1}0$ and $\bar{2}01$ (with or without small 001). Perfect 001 and distinct 010 cleavages are always present. The albite lamellar twinning is especially characteristic, but may be absent; other types of twinning may be present such as Carlsbad, Baveno, Manebach and pericline. H. = 6–6.5. G. = 2.61–2.76. F. = 1100° C. (albite) to 1550° C. (anorthite). Albite, oligoclase and and andesine are insoluble in acids (except HF); labradorite is somewhat attacked after long treatment, while anorthite is easily decomposed.

OPT. PROP.—The optic orientation varies considerably from albite to anorthite, but in the whole series the axis Z is nearer to a normal to 010 than is X or Y, and the bisectrix (Z) is visible in sections or cleavage pieces parallel to 010, though only one isogyre of the figure is seen from sections of anorthite, bytownite and even labradorite. In sodic plagioclase the axis X is approximately parallel to the axis *a*; in calcic plagioclase it varies considerably from this position. The positions of X, Y and Z and also of the optic axes A and B are shown in stereographic projection in Figs. 228–230. The optic sign changes three times in the plagioclase series, as shown in the table on page 292, and in Fig. 205. The dispersion of the axes is $\rho < v$ about Z from albite to andesine, and $\rho > v$ about Z from labradorite to anorthite; the dispersion of the bisectrices varies in the different types, but is never great, though showing two kinds, and therefore no symmetry, in accordance with the triclinic character of plagioclase.

The indices of refraction increase with increasing tenor of anorthite; the birefringence decreases from albite (0.011) to andesine (0.0065), and then increases to anorthite (0.013), as shown on page 293 and in Fig. 205.

	Albite $Ab_{100}An_0$	Oligoclase $Ab_{80}An_{20}$	Andesine $Ab_{60}An_{40}$	Labradorite $Ab_{40}An_{60}$	Bytownite $Ab_{20}An_{80}$	Anorthite Ab_0An_{100}
$2V =$	(+) 70°	(−) 86°	(+) 87°	(+) 78°	(−) 83°	(−) 77°
$N_g =$	1.536	1.547	1.557	1.567	1.576	1.589
$N_m =$	1.529	1.543	1.553	1.563	1.572	1.583
$N_p =$	1.525	1.539	1.550	1.559	1.567	1.576
$N_g - N_p =$	0.011	0.008	0.007	0.008	0.009	0.013
Extinction angles:						
⊥ X	+ 77°	90°	− 70°	− 62°	− 57°	− 59°
⊥ Y	+ 1°	+ 1°	− 5°	− 18°	− 30°	− 40°
⊥ Z	+ 21°	+ 6°	− 12°	− 35°	− 53°	− 64°
‖ 001	+ 3°	+ 2°	− 3°	− 9°	− 22°	− 40°
‖ 010	+ 20°	+ 6°	− 8°	− 22°	− 33°	− 38°
Max. ⊥ 010	− 20°	0°	+ 22°	+ 33°	+ 45°	+ 84°

Plagioclase is gray, white, greenish, reddish, bluish, yellowish, colorless; sometimes shows opalescence or play of colors. Luster vitreous. Colorless in thin section.

ALTER.—Plagioclase alters in many different ways under varying conditions (see pages 293–296), but the change to sericite is especially common. The alteration to kaolinite and other argillaceous minerals is also very common, while saussuritization of calcic plagioclase is widespread under certain conditions. Less common products of alteration include zeolites, calcite, prehnite, wollastonite, topaz, etc.

OCCUR.—Plagioclase is one of the commonest minerals of the earth's crust. It is a minor constituent of granite and an essential abundant constituent of gabbro, diorite, basalt, etc. One type (albite) is common in pegmatites and veins; the same one is abundant in many schists and gneisses. Both residual and regenerated plagioclases are not rare in sedimentary rocks.

DIAG.—See pages 296–312 and Figs. 231–243.

ALBITE TRICLINIC $a : b : c = 0.633 : 1 : 0.557$ $NaAlSi_3O_8$

$\alpha = 94° 31'$ $\beta = 116° 38'$ $\gamma = 87° 1'$

COMP.—Pure albite is $NaAlSi_3O_8$; natural albite contains up to 10 per cent $CaAl_2Si_2O_8$, and up to about 5 per cent $KAlSi_3O_8$, as well as minor amounts of other molecules, such as $BaAl_2Si_2O_8$.

PHYS. CHAR.—Crystals not rare, often tabular parallel to 010, sometimes elongated parallel to *c*, or to *b*. When twinned on the pericline law crystals may be tabular parallel to $\bar{1}01$. Albite twinning nearly always present; other common types of twinning include Carlsbad, pericline, Baveno, and Manebach. Perfect 001, distinct

010 and indistinct 110 cleavages. H. = 6–6.5. G. = 2.605 (pure) to 2.62. F. = 1100° C. (pure), 1100°–1250° C. (natural). Insoluble except in HF.

Opt. Prop.— The optic plane is about normal to 010, Z making an angle of 75° with it. A plane normal to Z makes an angle of 101° to 102° with 001 and lies in the obtuse angle between 001 and 010. Dispersion $\rho < v$ about Z with very weak horizontal and stronger inclined dispersion.

Color white, bluish, gray, reddish, greenish; sometimes opalescent on 001. Luster vitreous. Colorless in thin section.

Inver.— Changes to a high temperature form at about 900° C. according to Merwin.[39]

Alter.—More stable than anorthite under hydrothermal conditions. Changes to sericite, kaolinite, etc. (see pages 293–296). Forms as an alteration product of calcic plagioclase in the process of saussuritization; also of spodumenite and analcite.

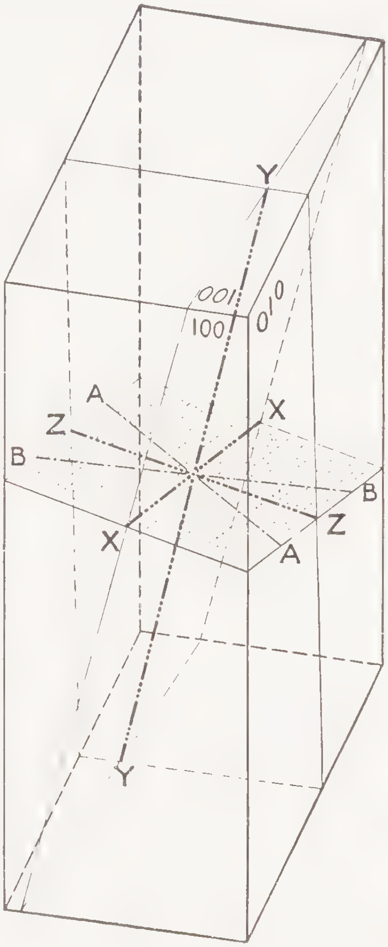


Fig. 265.—Optic orientation of albite.

	2V	N_g	N_m	N_p	$N_g - N_p$
Pure albite	(+) 70°	1.536	1.529	1.525	0.011
$Ab_{95}An_5$	(+) 76°	1.539	1.532	1.529	0.010
Extinction angles:	⊥ X	⊥ Z	‖ 001	‖ 010	Max. ⊥ 010
Pure albite	+ 77°	+ 21°	+ 3°	+ 20°	− 20°
$Ab_{95}An_5$	+ 75°	+ 20°	+ 2°	+ 18°	− 15°

Occur.—Albite is rare as a primary constituent of igneous rocks, but common in some pegmatites and veins, as well as in various schists. It is also found in some limestones.

DIAG.—See pages 296–312 and Figs. 231–243.

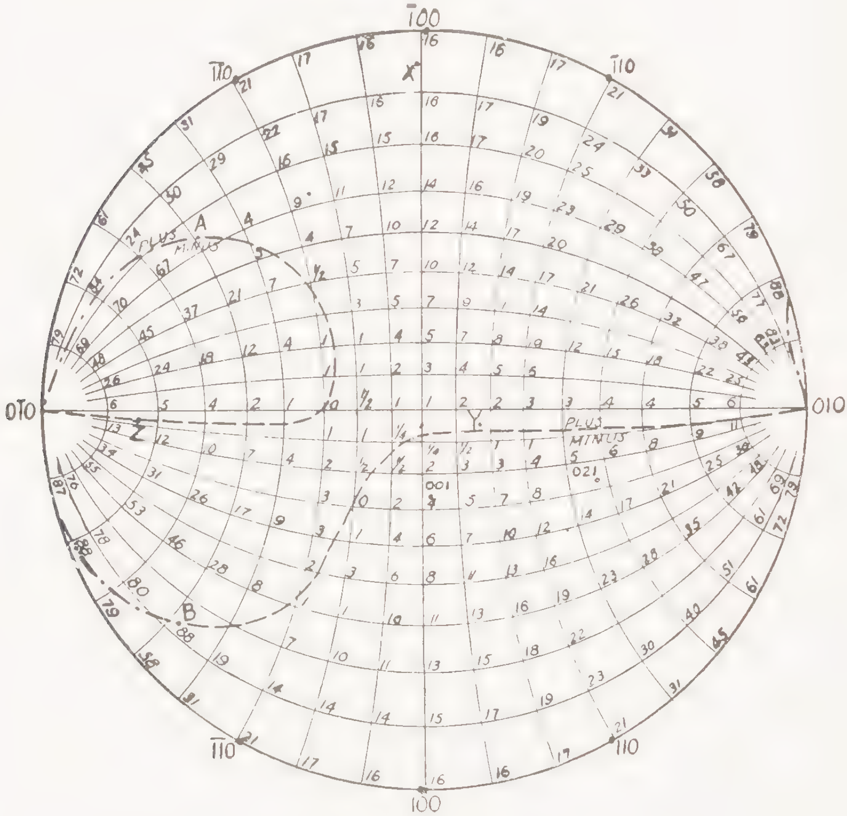


FIG. 266.—Stereographic projection showing extinction angles of albite. (After Duparc and Reinhard.)

OLIGOCLASE TRICLINIC Ab$_{90}$An$_{10}$ to Ab$_{70}$An$_{30}$

$a : b : c = 0.632 : 1 : 0.553$ $\alpha = 93° 31'$ $\rho = 116° 26'$ $\gamma = 89° 31'$

COMP.—Oligoclase in nature usually contains some KAlSi$_3$O$_8$ (up to about 7 per cent) and may contain minor amounts of BaAl$_2$Si$_2$O$_8$, etc.

PHYS. CHAR.—Crystals uncommon; usually lamellar or massive. Twinning as in albite. Perfect 001, distinct 010 and imperfect 110 cleavages. H. = 6. G. = 2.62–2.65. F. = 1120°–1380° C. Insoluble except in HF.

Opt. Prop.—The optic plane is nearly normal to 010, Z making an angle of 84° to 89° with it. The axis X makes an angle of 1° to 6° with 001, and an angle of 0° to 15° with 010. Dispersion $\rho < v$ about Z with crossed and inclined dispersion of the bisectrices.

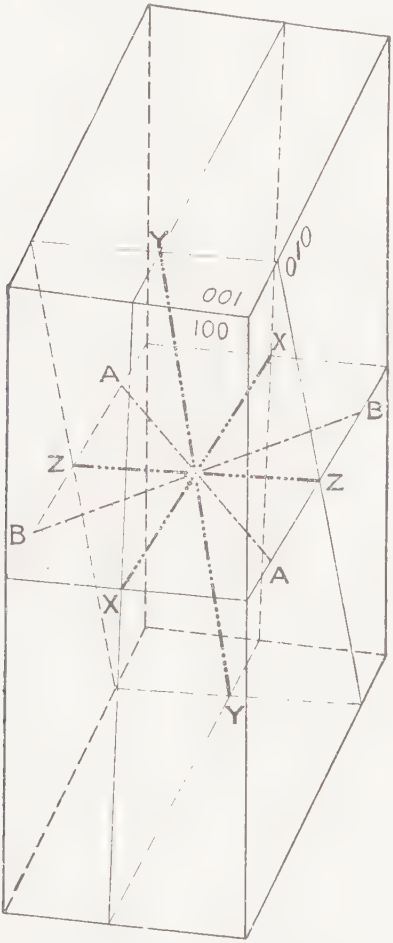


Fig. 267.—Optic orientation of oligoclase.

	2V	N_g	N_m	N_p	$N_g - N_p$
Albiclase ($Ab_{85}An_{15}$)	(+) 87°	1.544	1.540	1.536	0.008
Oligoclase ($Ab_{75}An_{25}$)	(−) 82°	1.549	1.546	1.542	0.007
Extinction angles:	⊥ X	⊥ Z	‖ 001	‖ 010	Max. ⊥010
Albiclase ($Ab_{85}An_{15}$)	+ 84°	+ 12°	+ 2°	+ 12°	− 8°
Oligoclase ($Ab_{75}An_{25}$)	− 86°	+ 3°	0°	+ 3°	+ 7°

Color white, grayish, greenish, reddish, sometimes with internal firelike reflections. Luster vitreous, colorless in thin section.

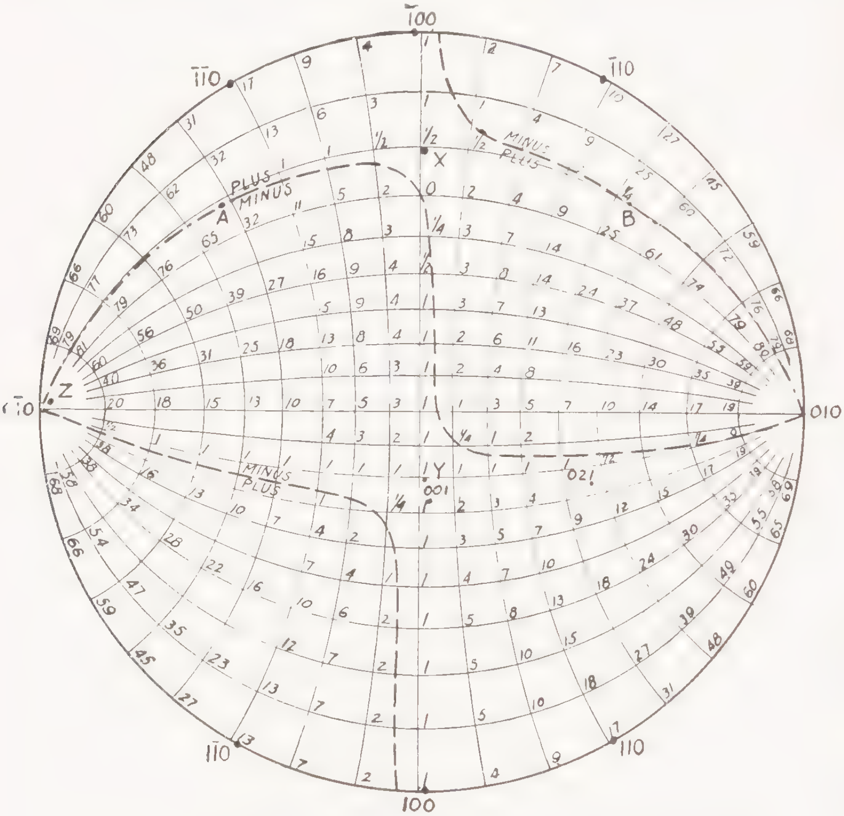


FIG. 268.—Stereographic projection showing extinction angles of oligoclase. (After Duparc and Reinhard.)

ALTER.—Similar to that of albite, but kaolinization is less common.

OCCUR.—Common in igneous rocks, especially those moderately rich in soda and in silica. Also common in gneiss and in schists.

DIAG.—See pages 296–312 and Figs. 231–243.

ANDESINE TRICLINIC $Ab_{70}An_{30}$ to $Ab_{50}An_{50}$

$a : b : c = 0.635 : 1 : 0.552$ $\alpha = 93° 27'$ $\beta = 116° 15'$ $\gamma = 89° 58'$

COMP.—Natural andesine usually contains some $KAlSi_3O_8$ (up to about 8 per cent), and may contain minor amounts of $BaAl_2Si_2O_8$, etc.

PHYS. CHAR.—Crystals rare; usually massive. Twinning as in albite. Perfect 001, distinct 010, and very poor 110 cleavages. H. =

6. G. = 2.65–2.685. F. = 1190°–1450° C. Insoluble in acids, or very slightly attacked.

Opt. Prop.—The optic plane is about normal to 010, the axis Z making an angle of 65° to 80° with that plane. The axis X makes an angle of 3° to 16° with 001 and an angle of 2° to 8° with 010. Dispersion $\rho < v$ about Z with distinct horizontal and weak inclined dispersion of the bisectrices.

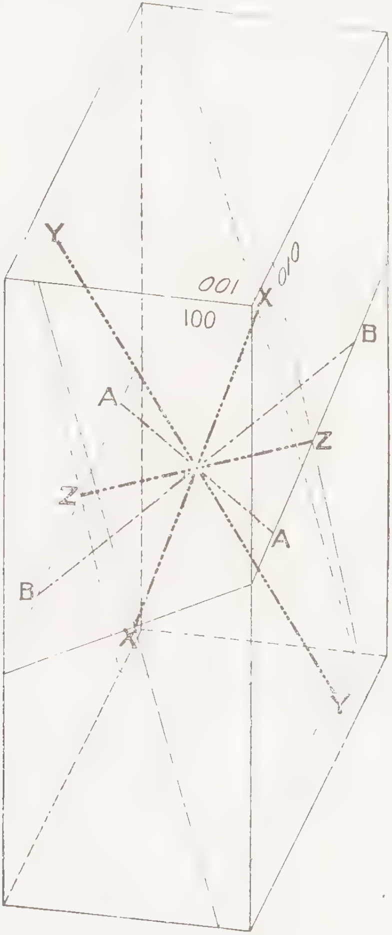


Fig. 269.—Optic orientation of andesine.

	2V	N_g	N_m	N_p	$N_g - N_p$
Andeclase ($Ab_{65}An_{35}$)	(−) 85°	1.554	1.551	1.547	0.007
Andesine ($Ab_{55}An_{45}$)	(+) 88°	1.560	1.556	1.553	0.007
Extinction angles:	⊥ X	⊥ Z	‖ 001	‖ 010	Max. ⊥ 010
Andeclase ($Ab_{65}An_{35}$)	− 73°	− 7°	− 2°	− 4°	+ 17°
Andesine ($Ab_{55}An_{45}$)	− 67°	− 19°	− 4°	− 12°	+ 25

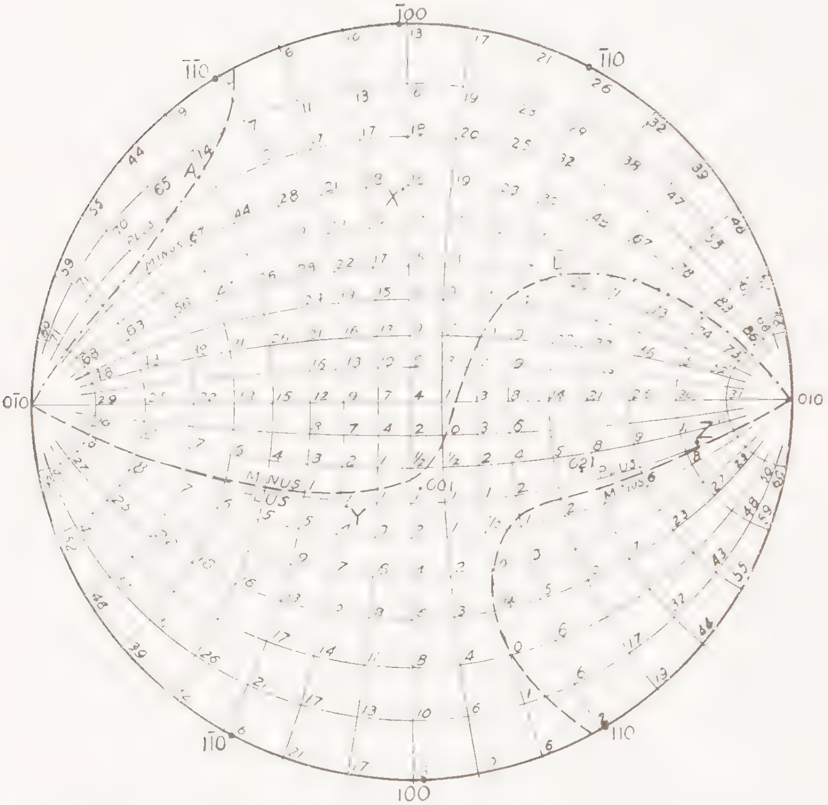


FIG. 270.—Stereographic projection showing extinction angles of andesine. (After Duparc and Reinhard.)

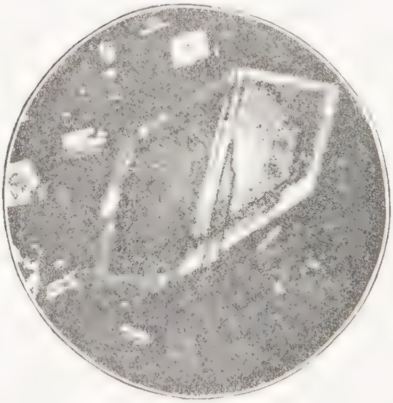


FIG. 271.—Photomicrograph of zonal andesine in thin section. ×50.

Color gray, white, greenish, yellowish, red. Luster vitreous; colorless in thin section.

ALTER.—Similar to that of oligoclase.

OCCUR.—Abundant in igneous rocks, especially those of medium content of silica; also common in gneisses and schists; rare in veins.

DIAG.—See pages 296–312 and Figs. 231–243.

LABRADORITE

TRICLINIC $Ab_{50}An_{50}$ to $Ab_{30}An_{70}$

$a : b : c = 0.638 : 1 : 0.555$ $\alpha = 93° 26'$ $\beta = 116° 6'$ $\gamma = 90° 15'$

COMP.—Natural labradorite usually contains some $KAlSi_3O_8$ (up to about 6 per cent), and may contain less $BaAl_2Si_2O_8$, etc.

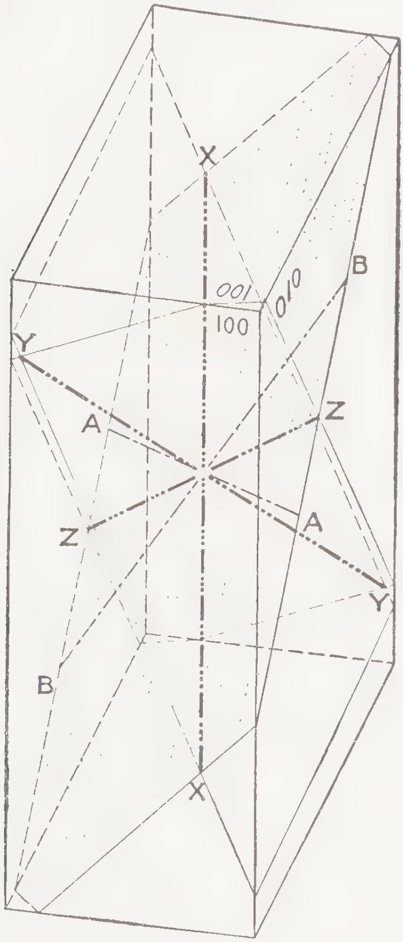


FIG. 272.—Optic orientation of labradorite.

PHYS. CHAR.—Crystals often tabular parallel to 010; usually massive, cleavable or granular. Twinning as in albite. Perfect 001, distinct 010 and imperfect 110 cleavages. H. = 6. G. = 2.685–2.715. F. = 1280°–1500° C. Only slightly soluble in hot HCl.

OPT. PROP.—The optic plane makes a large angle with 010, the axis Z making an angle of 55° to 65° with that plane, and 30° to 40°

with 001, while the axis X makes an angle of 15° to 25° with 001 and an angle of 8° to 20° with 010. Dispersion $\rho > v$ about Z with distinct crossed and weak inclined dispersion of the bisectrices.

	2V	N_g	N_m	N_p	$N_g - N_p$
Labradorite ($Ab_{45}An_{55}$)	(+) 75°	1.565	1.560	1.557	0.008
Labratownite ($Ab_{35}An_{65}$)	(+) 86°	1.570	1.565	1.561	0.009
Extinction angles:	⊥ X	⊥ Z	‖ 001	‖ 010	Max. ⊥ 010
Labradorite ($Ab_{45}An_{55}$)	− 63°	− 30°	− 8°	− 18°	+ 31°
Labratownite ($Ab_{35}An_{65}$)	− 60°	− 40°	− 12°	− 25°	+ 37°

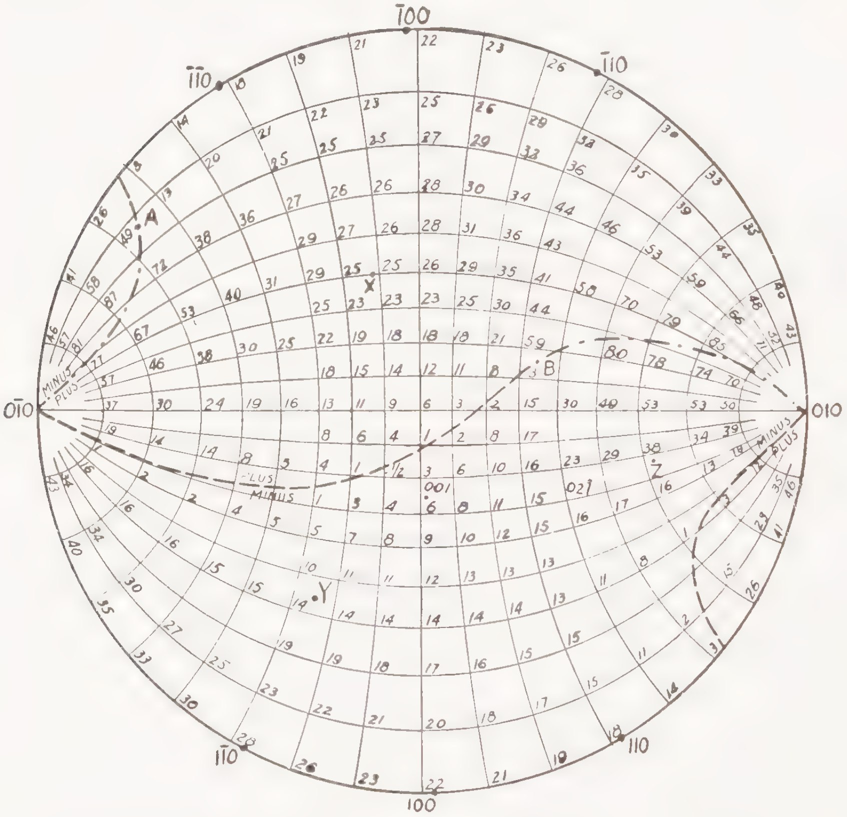


FIG. 273.—Stereographic projection showing extinction angles of labradorite. (After Duparc and Reinhard.)

Color gray, greenish, brown, colorless, white; often exhibits play of colors, especially on 010. Luster vitreous. Colorless in thin section.

INCL.—The colored varieties contain abundant inclusions of hematite or ilmenite, or, in other cases, black needles regularly arranged. In all varieties tiny inclusions of augite, amphibole, or magnetite are common, as well as liquid inclusions.

ALTER.—May change to sericite, or kaolinite; less commonly to gibbsite, scapolite, or prehnite; sometimes to "saussurite," which is an aggregate composed of zoisite, epidote, albite, etc., often with tremolite, quartz, garnet, rutile.

OCCUR.—Common in igneous rocks, especially those of moderate silica content; it may form plutonic rock by itself (plagioclasite or anorthosite). Also found in rocks produced by metamorphism, and as a residual constituent of sediments; rare in meteorites.

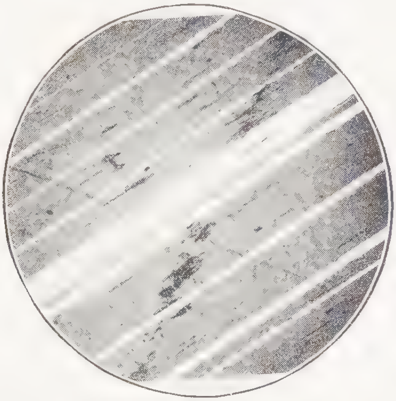


FIG. 274.—Photomicrograph of labradorite. (Taken by H. L. Alling—see *Jour. Geol.*, XXIX, 1921, p. 193.)

DIAG.—See pages 296–312 and Figs. 231–243.

BYTOWNITE TRICLINIC $Ab_{30}An_{70}$ to $Ab_{10}An_{90}$

$\alpha = 93° 22'$ $\beta = 116° 0'$ $\gamma = 90° 41'$

COMP.—Natural bytownite usually contains some $KAlSi_3O_8$ (up to about 5 per cent), and may contain very little $BaAl_2Si_2O_8$, etc.

PHYS. CHAR.—Crystals very rare; usually in microscopic lamellæ or massive. Twinning as in albite. Perfect 001 and distinct 010 cleavages. H. = 6. G. = 2.715–2.75. F. = 1390°–1530° C. Slowly soluble in hot HCl leaving a residue of gelatinous silica.

OPT. PROP.—The optic plane makes a large angle with 010, the axis Z being at about 42° to that plane and 45° to 001, while the axis X makes an angle of about 30° with 001 and about 35° with 010. Dispersion $\rho > v$ about Z with weak inclined and crossed dispersion of the bisectrices.

	2V	N_g	N_m	N_p	$N_g - N_p$
Bytownite ($Ab_{25}An_{75}$)	(−) 86°	1.574	1.570	1.565	0.009
Bytownorthite ($Ab_{15}An_{85}$)	(−) 79°	1.578	1.574	1.568	0.010
Extinction angles:	⊥ X	⊥ Z	‖ 001	‖ 010	Max. ⊥ 010
Bytownite ($Ab_{25}An_{75}$)	− 58°	− 49°	− 18°	− 31°	+ 42°
Bytownorthite ($Ab_{15}An_{85}$)	− 57°	− 57°	− 27°	− 35°	+ 48°

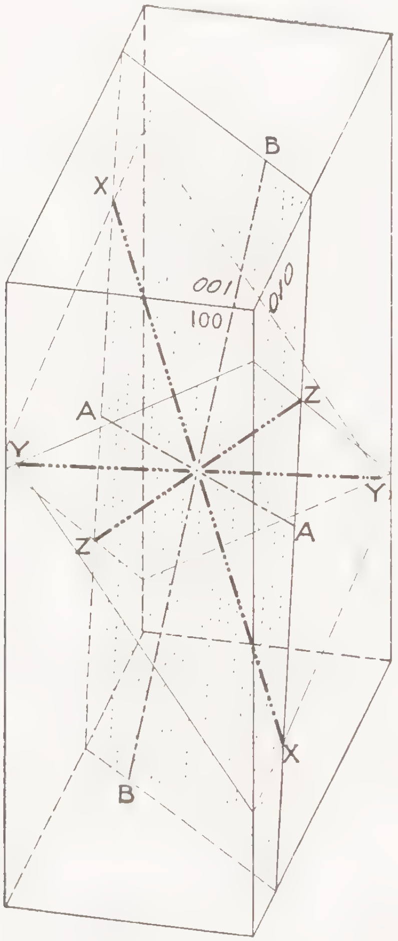


FIG. 275.—Optic orientation of bytownite.

Color gray, greenish, white, colorless. Luster vitreous. Colorless in section.

ALTER.—Similar to labradorite.

OCCUR.—Bytownite is the rarest of the plagioclase feldspars. It is found in basic igneous rocks, both plutonic and volcanic, and very rarely forms the rock called plagioclasite or anorthosite. Also formed by contact and regional metamorphism, and found in some meteorites.

DIAG.—See pages 296–312 and Figs. 231–243.

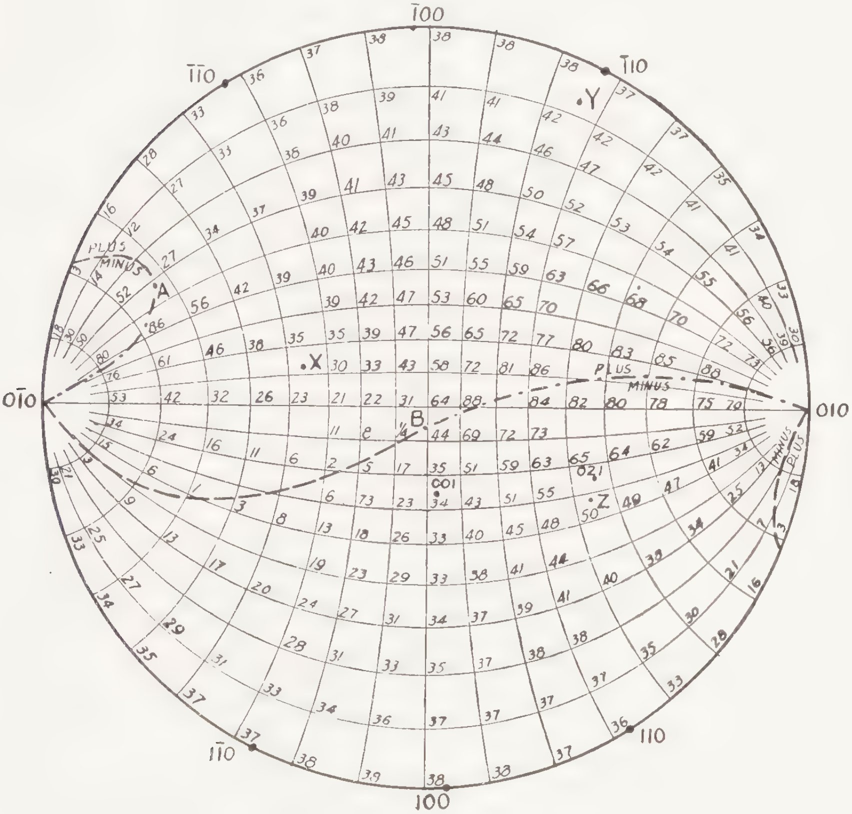


FIG. 276.—Stereographic projection showing extinction angles of bytownite. (After Duparc and Reinhard.)

ANORTHITE TRICLINIC $a : b : c = 0.635 : 1 : 0.551$ $CaAl_2Si_2O_8$

$\alpha = 93° 5'$ $\beta = 115° 54'$ $\gamma = 91° 34'$

COMP.—Pure anorthite is $CaAl_2Si_2O_8$; natural anorthite contains up to 10 per cent $NaAlSi_3O_8$, up to about 4 per cent $KAlSi_3O_8$ and still less $BaAl_2Si_2O_8$, etc.

PHYS. CHAR.—Crystals usually tabular parallel to 010; also equant or elongated parallel to *c*, or to *b*, commonly massive, lamellar or granular. Twinning as in albite. Perfect 001 and distinct 010 cleavages. H. = 6. G. = 2.75–2.765. F. = 1550° C. (pure), 1500°–

1550° (natural). Soluble in hot HCl with separation of gelatinous silica.

Opt. Prop.—The optic plane makes a large angle with 010, the axis Z being at about 43° to that plane and about 50° to 001, while the axis X makes an angle of about 32° with 010 and about 35° with 001. Dispersion $\rho > v$ with weak inclined and crossed dispersion of the bisectrices.

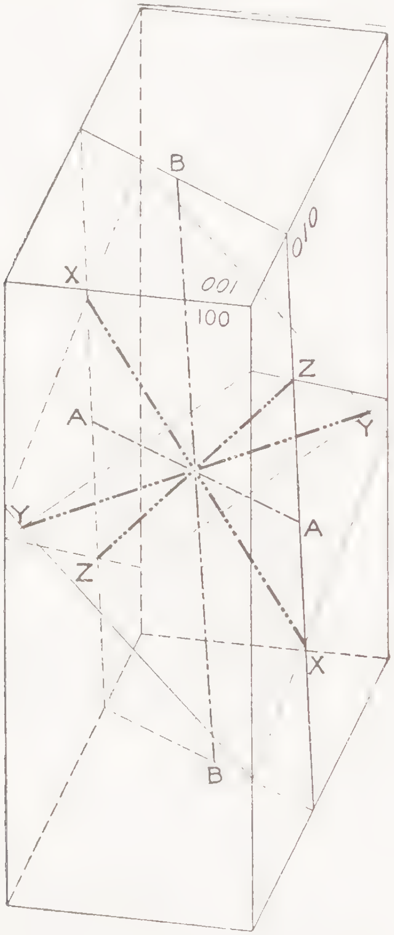


Fig. 277.—Optic orientation of anorthite.

	2V	N_g	N_m	N_p	$N_g - N_p$
Pure anorthite	(−) 77°	1.5885	1.5832	1.5755	0.013
Ab_5An_{95}	(−) 77°	1.585	1.580	1.573	0.012
Extinction angles:	⊥ X	⊥ Z	‖ 001	‖ 010	Max. ⊥ 010
Pure anorthite	− 59°	− 65°	− 40°	− 38°	+ 84°
Ab_5An_{95}	− [illegible]	− 62°	− 35°	− 37°	+ 56°

Color gray, white, reddish. Luster vitreous. Colorless in thin section.

ALTER.—Changes to sericite, kaolinite, zeolite, scapolite, prehnite, calcite, quartz, etc.; also to "saussurite"; rarely to wollastonite.

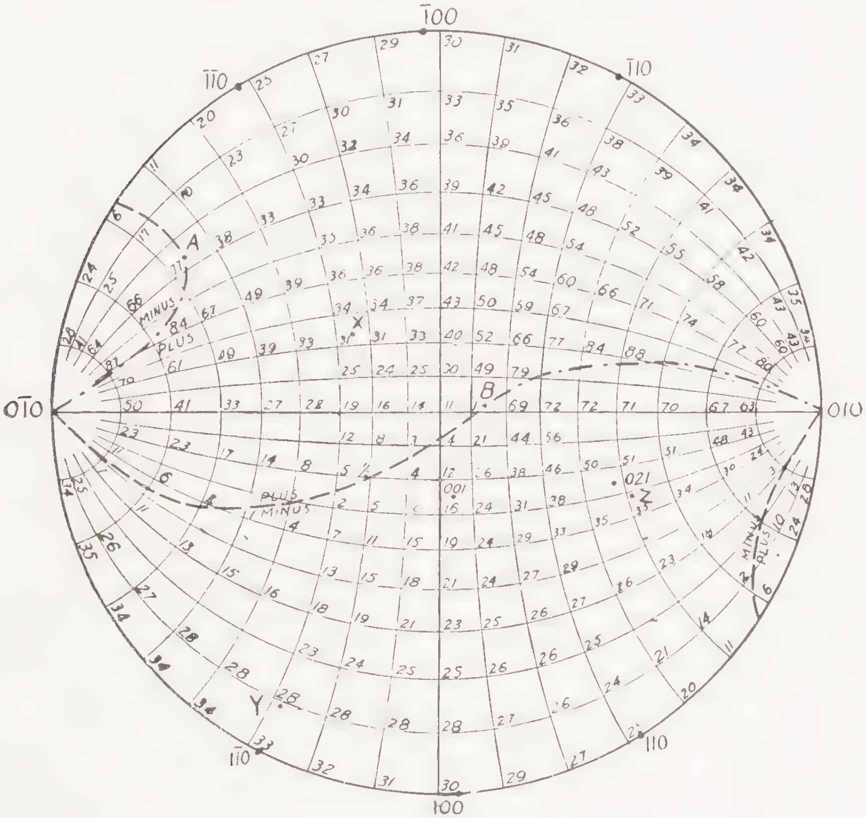


FIG. 278.—Stereographic projection showing extinction angles of anorthite. (After Duparc and Reinhard.)

OCCUR.—The presence of anorthite in igneous rocks implies little or no sodium, which is a rare condition. Anorthite may be formed by contact metamorphism; also known in meteorites.

DIAG.—Aside from the extremely rare celsian, anorthite has the strongest birefringence and the highest relief found among the feldspars. For other means of distinction see pages 296–312 and Figs. 231–243.

11. SILICATES OF Al (Cr, Fe''', Mn''') AND ONE OR MORE OTHER BASES, WITH HYDROGEN, FLUORINE, CHLORINE, OR SULPHUR

Hibschite ($H_4CaAl_2Si_2O_{10}$?) is isometric; crystals octahedral, etc., without cleavage. H. = 6. G. = 3.05. F. = 7. Easily attacked by acid. Isotropic with N = 1.67 ±. Also birefringent like garnet. Colorless or yellowish. Found in phonolite with melanite and in contact altered limestone. Very rare.

SODALITE GROUP

The sodalite group includes four minerals which are silicates of aluminum and sodium, and contain also some chlorine, sulphur or sulphate. They crystallize in isometric forms and may be related to garnet. Crystals are commonly dodecahedral, but a massive granular condition is not rare. Crystals may be twinned on 111, as in spinel. Imperfect dodecahedral cleavage. H. = 5–6. G. = 2.1–2.5. F. = 3–5. N = 1.48–1.51. Easily soluble even in weak acids. Sodalite proper yields NaCl in boiling water.

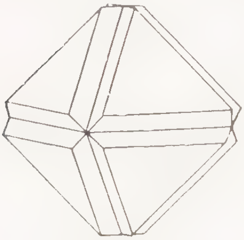


FIG. 279.—A penetration twin of hauynite.

The correct expressions for the composition are still in doubt. The following may be suggested:

Sodalite	Isometric	$n\mathrm{NaAlSiO_4 \cdot NaCl}$
Hackmanite	"	$n\mathrm{NaAlSiO_4 \cdot Na(Cl,S)}$
Noselite	"	$n\mathrm{NaAlSiO_4 \cdot NaNaSO_4}$
Hauynite	"	$n\mathrm{NaAlSiO_4} \cdot m\mathrm{CaCaSiO_4 \cdot NaNaSO_4}$
Lazurite	"	$n\mathrm{NaAlSiO_4} \cdot m\mathrm{CaCaSiO_4 \cdot (NaNaSO_4,NaCl,NaS_2)}$

SODALITE ISOMETRIC $n\mathrm{NaAlSiO_4 \cdot NaCl}$

PHYS. CHAR.—Crystals dodecahedral; often granular or nodular. Indistinct 110 cleavage. Twinning on 111 not common. H. = 5.5–6. G. = 2.14–2.4. F. = 3.5–4 to colorless glass. Powdered material yields NaCl in boiling water. Gelatinizes even in acetic acid.

OPT. PROP.—Isotropic with N = 1.483 (to 1.487); rarely birefringent about inclusions. Colorless, gray, yellow, blue, greenish, pale red. In thin section colorless, yellow, blue, pink. Some samples are pink when freshly broken, fading quickly on exposure to light.[1]

ALTER.—Alters easily to a fibrous mass of zeolites, especially natrolite, or to a lamellar aggregate of sericite, hydrargillite, diasporite, etc., or to cancrinite, garnet, or a fibrous apparently amorphous pink or brown substance; calcite and limonite may form at the same time.

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[1] T. L. Walker and A. L. Parsons: *Am. Mineral.*, X, 1925, p. 66.

Occur.—In igneous rocks rich in soda, or rarely in limestone modified by such rocks. Often associated with nephelite, from which it may form by alteration.

Diag.—The minerals of the sodalite group are distinguished by their very low refractive index from most other isotropic substances, the chief exceptions being volcanic glass, fluorite, leucite and analcite. They are distinguished from these substances by their form, cleavage, absence of complex twinning and chemical reactions. The minerals of the sodalite group may be distinguished from one another by the following test: the mineral is covered on a glass slide with a little nitric acid, which is allowed to evaporate slowly; in a short time crystals of NaCl may form, indicating sodalite, or of $CaSO_4 \cdot 2H_2O$, indicating hauynite, or of neither before, and both after, addition of $CaCl_2$, indicating noselite; if H_2S (which will blacken silver) is evolved during the attack by nitric acid, it indicates lazurite, which is further distinguished by its mode of occurrence as a contact mineral in limestone. Also, sodalite is usually colorless in thin section; the others are usually colored in section, lazurite being always blue.

Hackmanite is a variety of sodalite containing about 6 per cent of the NaS-silicate molecule. It is isotropic with N = 1.487. Color reddish violet, fading on exposure to light. Found in an alkaline igneous rock. Very rare.

NOSELITE (*Nosean*) Isometric $n\text{NaAlSiO}_4 \cdot \text{NaNaSO}_4$

Phys. Char.—Similar to sodalite. H. = 5.5. G. = 2.25–2.4. F. = 5 to a white glass. Gelatinizes easily with acid.

Opt. Prop.—Nearly always isotropic with N = 1.48–1.495; rarely birefringent if inclusions are present (due to strain?). Colorless, white, gray, lavender blue, or yellowish, brown, red or black from inclusions or alteration products. In thin section the blue color may be very bright; it is usually irregularly distributed.

Incl.—Microscopic inclusions, often abundant, sometimes irregularly arranged in zones or along certain axes. They may be gaseous, liquid, vitreous or crystalline; the last may be magnetite or ilmenite, which may be of definite orientation and very abundant.

Alter.—Similar to sodalite. Ferriferous inclusions may alter to limonite, giving a yellow or brown color.

Occur.—Exclusively in phonolites and similar igneous rocks.

Diag.—See sodalite.

HAUYNITE (*Hauyne*) Isometric $n\text{NaAlSiO}_4 \cdot m\text{CaCaSiO}_4 \cdot \text{NaNaSO}_4$

Phys. Char.—Similar to sodalite. H. = 5.5–6. G. = 2.4–2.5. F. = 4.5 to a white glass. Gelatinizes easily with acid.

Opt. Prop.—Nearly always isotropic with N = 1.496–1.51; rarely birefringent if inclusions are present. The index varies with the tenor of calcium. Usually blue;

also green, or, by alteration, yellow to red. Inclusions may produce a gray to black color. In thin section the blue color may be very bright; it is often irregularly distributed.

Incl. and Alter.—Similar to noselite.

Occur.—Exclusively in phonolites, theralites, and related igneous rocks, usually associated with nephelite or leucite.

Diag.—See sodalite.

LAZURITE Isometric $n\text{NaAlSiO}_4 \cdot m\text{CaCaSiO}_4 \cdot (\text{NaNaSO}_4, \text{NaCl}, \text{NaS}_2)$

Comp.—Formula quite uncertain; the sulphide may be NaS_3; in the artificial substance, called *ultramarine*, NaCl is and Ca_2SiO_4 and Na_2SO_4 may be absent, and the sulphide may be Na_2S, NaS, or NaS_2.

Phys. Char.—Similar to sodalite. H. = 5-5.5. G. = 2.38-2.45. F. = 5 to a white glass. Gelatinizes easily with acid and yields H_2S.

Opt. Prop.—Nearly always isotropic with N = 1.50 ±. Color blue both in mass and in thin section.

Occur.—Exclusively in contact altered limestone.

Diag.—See sodalite.

VESUVIANITE (*Idocrase*) Tetragonal $c = 0.537$ $Ca_2AlSi_2O_7(OH)$?

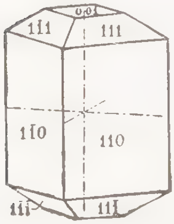

Fig. 280.—A crystal habit of vesuvianite.

Comp.—Formula uncertain; composition variable with some Fe, Mg, Na, Ti, B. F, etc.

Phys. Char.—Crystals often prismatic; massive. Indistinct 110 cleavage. H. = 6.5. G. = 3.35-3.45. F. = 3 with intumescence, but changes before fusion. Partly decomposed by HCl

Opt. Prop.—Uniaxial negative; also biaxial with 2E = 30°-60°, and then basal sections show sectors, often four diagonal, in each of which the optic plane is normal to the edge. The optic angle decreases with rise of temperature, and in some cases with pressure. Birefringence usually about 0.004. *Viluite* is a rare variety which is positive and usually biaxial; it contains 2-4 per cent B_2O_3.

Vesuvianite	$N_o = 1.705-1.736$	$N_e = 1.701-1.732$	$N_o - N_e = 0.001-0.006$
Viluite	$N_o = 1.716 \pm$	$N_e = 1.717-1.721$	$N_e - N_o = 0.001-0.005$

The relations between optic properties and composition have not yet been worked out.

Color brown to red, green, rarely yellow to pale blue. Streak white. The color varies chiefly with the tenor and state of oxidation of the iron; thus, yellow crystals contain up to 1 per cent FeO and about 4 per cent Fe_2O_3; brown crystals contain more than 2 per cent FeO and about the same tenor of Fe_2O_3.

In thin section colorless, pale brown, or green, the colors often in zones or patches. Pleochroism not noticeable in thin section, but in thick plates variable, as follows:

Mass color	X	Z
Brown	brownish yellow to brownish gray	yellowish brown to yellowish green
Red	light rose red to peach blow red	colorless to light gray
Green	light flesh gray, yellow, or green	colorless to greenish yellow
Blue	nearly colorless	dark blue

Occur.—Confined to contact zones, and commonly with garnet, diopside, wollastonite, epidote, etc., in altered limestone. Also in schists, gneiss, amphibolite, and even igneous rocks (pegmatite and theralite) in contact zones.

DIAG.—Characterized by high refringence, very weak birefringence, usual negative sign and elongation, crystal form and frequent zonal arrangement of colors. Differs from zoisite in the absence of cleavage, of abnormal dispersion, and of large optic angle, from melilite in higher refringence and colors, and from andalusite in higher refringence, weaker birefringence and absence of large optic angle.

SCAPOLITE (or Wernerite) GROUP

The minerals of the scapolite group are silicates of aluminum with calcium or sodium or both and more or less chlorine or hydroxyl or carbonate or sulphate radical. They crystallize in tetragonal forms, and have a hardness of 5 to 6.5 and a density of 2.5 to 2.8. Like soda-lime feldspars they form a continuous series with gradual variation in composition and physical characters. The composition of the series may be explained as due to mutual crystal solution of two molecules which are themselves variable to a small extent; these are known as the marialite molecule ($Na_4Al_3Si_9O_{24}Cl$ = Ma) and the meionite molecule ($Ca_4Al_6Si_6O_{27}C$ = Me). The close relation in composition to the plagioclase feldspars may be made apparent by writing these molecules as follows: Ma = $3NaAlSi_3O_8 \cdot NaCl$; Me = $3CaAl_2Si_2O_8 \cdot CaCO_3$. It seems that the NaCl of marialite may be replaced [2] to a limited extent by $NaHSO_4$ or $NaHCO_3$ or KOH,[3] while the $CaCO_3$ of meionite may be replaced in part by $CaSO_4$, and perhaps [4] CaF_2; also K may replace Na to some extent.[5]

The specific gravity, solubility, refringence and birefringence all decrease with increase of silica and soda and decrease of lime and alumina. Some of these relations [6] are shown in Fig. 281; the sulphate radical [7] seems to cause a decrease in the birefringence, by lowering N_o about .004 for each weight per cent of SO_3. From the few carefully studied samples [3] high in potassa and water, it is probable that these lower each index about .005, and the specific gravity about .02, for each per cent K_2O (assuming about 0.75 per cent H_2O with it).

The chief scapolite series may be divided as follows:

Marialite	$c = 0.446$ (for pure Ma)	$Ma_{100}Me_0$ to $Ma_{80}Me_{20}$
Dipyrite	$c = 0.444$	$Ma_{80}Me_{20}$ to $Ma_{50}Me_{50}$
Mizzonite	$c = 0.442$	$Ma_{50}Me_{50}$ to $Ma_{20}Me_{80}$
Meionite	$c = 0.439$ (for pure Me)	$Ma_{20}Me_{80}$ to Ma_0Me_{100}

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[2] L. M. Borgström: *Zeit. Kryst.*, LIV, 1915, p. 238. N. Sundius: *Bull. Geol. Inst.*, Upsala, XV, 1916, p. 1.

[3] T. Barth: *Sært. Norsk Geol. Tids.*, VIII, 1924, p. 93.

[4] E. V. Shannon: *Proc. U. S. Nat. Mus.*, LVIII, 1920, p. 481.

[5] V. M. Goldschmidt: *Die Kontaktmetamorphose im Kristianagebiet*, 1911, p. 315.

[6] A. N. Winchell: *Am. Mineral.*, IX, 1924, p. 108.

[7] R. Brauns: *N. Jahrb. Min.*, 1917, p. 9.

MARIALITE TETRAGONAL $c = 0.446$ $Ma_{100}Me_0$ to $Ma_{80}\ Me_{20}$

PHYS. CHAR.—Crystals long prismatic, striated vertically. Distinct 110 cleavage. G. = 2.55–2.60. H. = 5.5–6. F. = 1100°–1200° C. Nearly insoluble in acids.

OPT. PROP.—Natural crystals uniaxial negative with refringence and birefringence similar to those of quartz. From Fig. 281 it may be inferred that pure $NaCl \cdot 3NaAlSi_3O_8$ would be uniaxial positive. $Ma_{85}Me_{15}$ has $N_o = 1.546$, $N_e = 1.540$, $N_o - N_e = 0.006$ according to Himmelbauer. Colorless or stained by impurities.

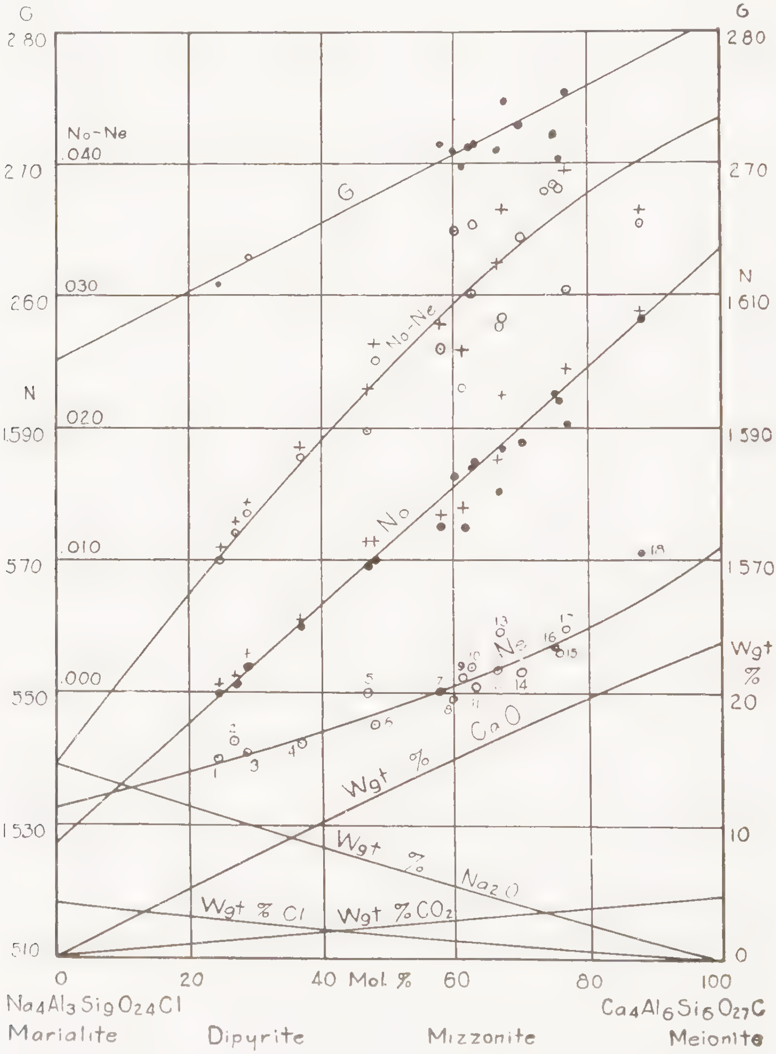

FIG. 281.—Variations of composition and physical characters in the scapolite series.

INCL.—Inclusions may be abundant.

Alter.—May change to mica, clinochlorite, calcite, quartz, chabazite, stilbite, or an isotropic material.

Occur.—In volcanic rocks in Italy. Rare.

Diag.—Differs from other scapolites in lower refringence and weaker birefringence, and from quartz in the presence of cleavages and contrary sign (in all known cases).

DIPYRITE Tetragonal $c = 0.444$ $Ma_{80}Me_{20}$ to $Ma_{50}Me_{50}$

Phys. Char.—Crystals long prismatic, vertically striated; also massive. Distinct 100 cleavage. H. = 6. G. = 2.60–2.68. F. = 1160° ± C. Slightly attacked by acids.

Opt. Prop.—Uniaxial negative with $N_o = 1.55–1.57$, $N_e = 1.54–1.55$, $N_o - N_e = 0.008–0.025$. See Fig. 281. Colorless, milky, greenish, gray, violet, black. Distinct color always due to impurities. Colorless in section.

Incl.—Inclusions are commonly abundant and may occupy more space than the enclosing mineral. In limestone they may be calcite or carbonaceous matter, though the latter may be lacking elsewhere in the rock. Other inclusions may be quartz, mica, feldspar, amphibole, garnet, etc. In mica schists the inclusions are commonly mica, tourmaline, rutile, actinolite, etc.; these may be oriented parallel with the vertical axis of the dipyrite. In contact rocks, the inclusions may be mica, pyroxene, tourmaline, etc.; they are usually unoriented.

Alter.—Common alteration products are mica, (nearly) colorless clinochlorite, calcite, quartz, chabazite, stilbite, and an isotropic substance. By recrystallization under anamorphic conditions dipyrite may be changed to a mixture of forsterite and spinel.

Occur.—In schists and contact rocks, both exomorphosed sediments and endomorphosed igneous rocks.

Diag.—Distinguished from other scapolites (except the rare marialite) by lower refringence and weaker birefringence; differs from quartz in sign, cleavages, and stronger birefringence.

MIZZONITE Tetragonal $c = 0.442$ $Ma_{50}Me_{50}$ to $Ma_{20}Me_{80}$

Phys.—Crystals often coarse and rough; also massive. Distinct interrupted 100 and indistinct 110 cleavages. H. = 5–6. G. = 2.68–2.75. F. = 1200° ± C. Imperfectly decomposed by HCl.

Opt. Prop.—Uniaxial negative with $N_o = 1.57–1.60$, $N_e = 1.55–1.56$, $N_o - N_e = 0.025–0.040$. See Fig. 281. Color white, gray, bluish, greenish, reddish. Colorless in section.

Incl. and Alter.—See dipyrite.

Occur.—Especially in contact-altered limestone, often with diopside, garnet, titanite, etc. The commonest of the scapolite series.

Diag.—Differs from meionite in its lower relief and weaker birefringence, and from other scapolites in its high relief and stronger birefringence.

MEIONITE Tetragonal $c = 0.439$ $Ma_{20}Me_{80}$ to Ma_0Me_{100}

Phys. Char.—Crystals short prismatic. Distinct 100 and indistinct 110 cleavages. H. = 5.5–6. G. = 2.75–2.80. F. = 1160° C. Decomposed by HCl.

Opt. Prop.—Uniaxial negative with $N_o = 1.59$ to 1.61, $N_e = 1.56$ to 1.57, $N_o - N_e = 0.035$ to 0.040. See Fig. 281. Colorless to white.

Incl. and Alter.—See dipyrite.

Occur.—In cavities in limestone in lava at Vesuvius; also rarely in gneiss and schist.

Diag.—Differs from other scapolites in higher relief and stronger birefringence.

Narsarsukite ($Na_6FeFTi_2Si_{12}O_{32}$?) is tetragonal with $c = 0.524$; crystals 001 tablets or short prismatic with perfect 110 cleavages. H. = 7. G. = 2.75. Easily fusible.

Soluble only in HF. Uniaxial positive with $N_o = 1.5532$, $N_e = 1.5842$, $N_e - N_o = 0.031$. Color honey yellow to reddish; colorless in thin section, but in thick plates irregularly colored with X = colorless, Z = reddish yellow. Abundant in pegmatite at Narsarsuk, Greenland.

Leifite [8] $\{Na_4(AlF)_2Si_9O_{22}\}$ is hexagonal; crystals acicular, deeply striated, with distinct prismatic cleavage. H. = 6. G. = 2.57. F. = easy. Insoluble in acids. Uniaxial positive with $N_o = 1.5177$, $N_e = 1.5224$, $N_e - N_o = 0.0044$ (calc.), 0.0047 (obs.). Colorless. Inclusions may be abundant, at times arranged in vertical lines. Found in pegmatite with microcline, acmite, zinnwaldite, calcite. Very rare.

Milarite $(HKCa_2Al_2Si_{12}O_{30})$ is hexagonal with $c = 0.662$; crystals prismatic without cleavage. H. = 5.5–6. G. = 2.57. F. = 3. Insoluble in acid. Strictly uniaxial (negative) at high temperature; biaxial with 2V = small at ordinary temperature, basal sections showing six radial segments; a central part may be uniaxial. $N_o = 1.532$, $N_e = 1.529$, $N_o - N_e = 0.003$ (Larsen); $N_o = 1.536$, $N_o - N_e =$ about 0.001 (Müller [9]). Pale green to colorless. Found in pegmatite in Switzerland. Very rare.

Astrolite $\{H_2(Na,K)_2Fe''(Al,Fe''')_2Si_5O_{16}?\}$ is orthorhombic; globular forms with stellate structure; distinct cleavage parallel to plates. H. = 3.5. G. = 2.78. F. = 3.5. Insoluble in acid. X is normal to plates. (−) 2V = 30°, $\rho > v$, $N_g = 1.597$, $N_m = 1.594$, $N_p = 1.570$, $N_g - N_p = 0.027$. Color greenish yellow with X = nearly colorless, Y = Z = siskin-green. Found in xenoliths in diabase in Saxony. Very rare.

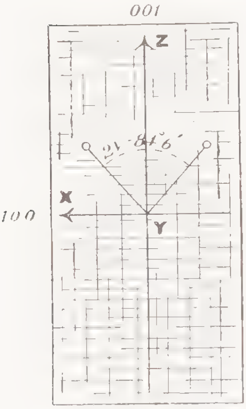

Fig. 282.—Optic orientation of lawsonite.

Lawsonite $(H_4CaAl_2Si_2O_{10})$ is orthorhombic with $a : b : c = 0.665 : 1 : 0.738$; crystals prismatic, 001 tabular, or varied, with perfect 010 and 001 and imperfect 110 cleavages. Twinning on 110. H. = 8. G. = 3.1. F. = 4. Insoluble in acid. Gelatinizes with acids after fusion. G. after fusion = 2.56. The optic plane is parallel to 010; X = *a*. (+) 2V = 84°, $\rho > v$, strong; $N_g = 1.684$, $N_m = 1.674$, $N_p = 1.665$, $N_g - N_p = 0.019$. Colorless to bluish; colorless in thin section, but in thick plates X = blue, Y = yellowish, Z = colorless. Found in schists in California, the Alps, Corsica, etc.; also as a secondary product of plagioclase in saussuritized gabbro. Differs from zoisite and andalusite by its stronger birefringence, from cordierite by its higher refringence, and from scapolite by its biaxial character. Unusually high relief as compared with most secondary minerals.

PREHNITE Orthorhombic $a : b : c = 0.842 : 1 : 1.154$ $H_2Ca_2Al_2Si_3O_{12}$

Comp.—Alumina may be replaced, in part, by Fe_2O_3.

Phys. Char.—Crystals 001 tablets or prismatic; often columnar or lamellar massive. Distinct 001 cleavage. H. = 6–6.5. G. = 2.80–2.95. F. = 2 with intumescence to a blebby enamel. Slowly soluble in HCl.

Opt. Prop.—The optic plane is parallel to 010; X = *a*. (+) 2V = 66°–69° (or much less), $\rho > v$ weak, to $\rho < v$ extreme with 2V very small. Elongation negative when tabular, positive when prismatic.

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[8] O. B. Böggild: *Zeit. Kryst.*, LV, 1920, p. 425.

[9] *N. Jahrb. Min. Beil. Bd.*, XLIV, 1921, p. 402.

	Lacroix[10]	Eckermann[11]	Laitakari[12]	Shannon[13]	Shannon[14]
Fe_2O_3 =	0.00		0.95	2.10	6.93
(+) 2V =	?	68° 40′	65° 52′	Mod.	0°–30°
N_g =	1.649	1.646	1.645	1.652	1.655
N_m =	1.626	1.625	1.624	1.629	1.640
N_p =	1.616	1.615	1.615	1.626	1.635
$N_g - N_p$ =	0.033	0.031	0.030	0.026	0.020

Color pale green, gray, white; colorless in section.

Optic anomalies are not uncommon. Some sections show fine twinning lamellæ like those of microcline; basal sections may show bands parallel and normal to 100, the optic plane being at right angles in the two sets of bands; it is believed that these bands may become submicroscopic causing the optic angle to appear much smaller, the dispersion to be abnormal ($\rho < v$, or even crossed, strong), and, in some cases, incomplete extinction and abnormal interference colors.

Incl.—The green color may be due to abundant inclusions of chlorite; limonite gives a yellowish tint; asbestus gives a white color.

Occur.—Chiefly in cavities in basic igneous rocks associated with zeolites, calcite, datolite, pectolite, etc. Also in schists and amphibolites; also in pegmatite; and in veins. Usually secondary.

Diag.—Differs from other colorless alteration products by its high relief and strong birefringence; thomsonite is fibrous with ± elongation; lawsonite has more cleavages and weaker birefringence; datolite has stronger birefringence and opposite sign; andalusite, topaz and wollastonite have weaker birefringence.

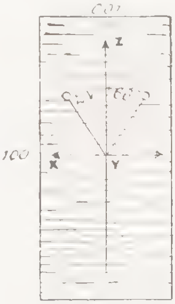

Fig. 283.—Optic orientation of prehnite.

Cebollite ($H_2Ca_5Al_2Si_3O_{16}$?) is orthorhombic (?) fibrous. H. = 5. G. = 2.96. F. = 5 to clear glass. Gelatinizes with HCl. Parallel extinction. (+) 2V = 58° ±, $N_g = 1.628$, $N_m = 1.60$, $N_p = 1.595$, $N_g - N_p = 0.033$. Color white. An alteration product of melilite. Rare.

STAUROLITE ORTHORHOMBIC $HFeAl_5Si_2O_{13}$?

$a : b : c = 0.473 : 1 : 0.682$

Phys. Char.—Crystals short prismatic with 001 and 010; cruciform twins common, both on 032 giving an apparent rectangular cross, and on 232 giving a cross at 60° 31′. Distinct 010 cleavage. H. = 7–7.5. G. = 3.65–3.77. F. = 7. Slowly attacked by H_2SO_4; insoluble in cold HF.

Opt. Prop.—The optic plane is parallel to 100, and the acute bisectrix, Z, is normal to 001. The optic angle varies from about 80°

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[10] *Minéraux des Roches*, 1888.

[11] *Geol. För. Förh. Stockholm*, XLIV, 1922, p. 376.

[12] *Geol. För. Förh. Stockholm*, XXXVI, 1914, p. 432.

[13] *U. S. Nat. Mus. Bull.* 131, 1926, p. 330.

[14] *Proc. U. S. Nat. Mus.*, LXVI, 1924, p. 62.

about Z to very nearly 90°, an angle of 86° to 89° being common. Dispersion $\rho > v$ weak. The optic angle decreases with rise of temperature.

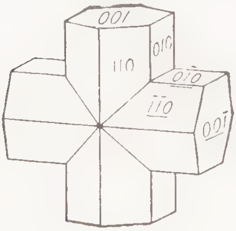

FIG. 284.—Cruciform twin of staurolite.

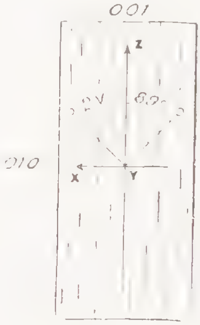

FIG. 285.—Optic orientation of staurolite.

	Lacroix [15]	St. Gotthard Hörner [16]	Petersdorf Hörner [16]	Bavaria Hörner [16]
(+) 2V =	88° 46′	88° 21′	86° 59′	80° 39′
N_g =	1.746	1.751	1.756	1.762
N_m =	1.741	1.745	1.750	1.754
N_p =	1.736	1.739	1.744	1.747
$N_g - N_p$ =	0.010	0.012	0.012	0.015
G. =	?	3.753	3.778	3.759
Fe_2O_3 =	?	1.80	?	2.33

Color dark reddish brown, yellowish brown, brownish black. In thin section variable pleochroism, greater around inclusions, with X = colorless, Y = pale yellow, Z = golden yellow.

INCL.—Abundant inclusions of quartz are common; rutile, tourmaline, garnet, etc., also occur. In limestones carbonaceous inclusions are found, in rare cases regularly arranged, much as in chiastolite.

ALTER.—May change to a green mica of large optic angle, or to chlorite.

OCCUR.—In schists, phyllites, etc., with garnet, cyanite, andalusite, sillimanite. Also in endomorphosed igneous rocks and exomorphosed sediments.

DIAG.—In thin section characterized by strong absorption in golden yellow tints, parallel extinction, and rather weak birefringence. The crystal forms and twins are also distinctive.

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[15] *Minéraux des Roches*, 1888, p. 284.

[16] *Inaug. Diss. Heidelberg*, 1915.

ILVAITE

ORTHORHOMBIC $a : b : c = 0.666 : 1 : 0.443$ $HFe''_2Fe'''Si_2O_9$

PHYS. CHAR.—Crystals vertically striated prisms with distinct 001 and 010 cleavages. H. = 5.5–6. G. = 3.8–4.1. F. = 2.5. Gelatinizes with acid.

OPT. PROP.—The optic plane is 100 and the acute bisectrix Z is normal to 001. Nearly opaque in thin section and optic data therefore incomplete.

(−) 2E = 60° ±, $\rho < v$ strong, $N_g = 1.91–1.92$ (Larsen), $N_m = 1.89$ (Wülfing), $N_g - N_p$ = strong. Also optically positive according to Böggild.

Color iron or grayish black; intensely pleochroic in thin section; pleochroic also in reflected light, as follows:

Transmitted light	Reflected light
X = clear brown to brownish yellow	brown
Y = brown, nearly opaque	brown
Z = dark green to opaque	green

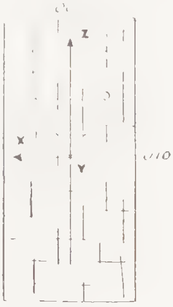

FIG. 286.—Optic orientation of ilvaite.

ALTER.—Alters to limonite.

OCCUR.—In iron ore in Tuscany; as a contact mineral in Nassau; an alteration product of acmite and arfvedsonite in Greenland. Rare.

DIAG.—The crystal form is rather distinctive. In thin section it is brown (if translucent) and strongly pleochroic like enigmatite, from which it differs by its parallel extinction and maximum absorption parallel to the best cleavage.

Carpholite ($H_4MnAl_2Si_2O_{10}$) is orthorhombic; crystals unknown; fibrous, with 110 cleavage at 68.5°. H. = 5–5.5. G. = 2.9. F. = 3.5. Nearly insoluble in HCl. The optic plane is parallel to 100; Z = c. (−) 2V = 60° ±, $N_g = 1.64 \pm$, $N_m = 1.63$, $N_p = 1.62 \pm$, $N_g - N_p = 0.022$. Elongation positive. Color straw to wax yellow; in thin section colorless to yellow with X = Y = golden yellow to colorless, Z = colorless. The maximum absorption is therefore normal to the elongation. Found in quartz and metalliferous veins; rare. Distinguished from ardennite by positive elongation, lower relief and fusibility.

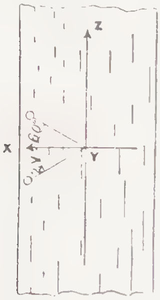

FIG. 287.—Optic orientation of carpholite.

Harstigite $\{5(Mn,Mg)O \cdot 10CaO \cdot 2Al_2O_3 \cdot 12SiO_2 \cdot 4H_2O\}$ is orthorhombic with $a : b : c = 0.715 : 1 : 1.015$. Crystals short prismatic without cleavage. H. = 5.5. G. = 3.05. After ignition soluble in HCl. Optic plane is 010; X = c. (+) 2V = 52°, $\rho < v$ weak. $N_g = 1.683$, $N_m = 1.68$, $N_p = 1.678$, $N_g - N_p = 0.005$. Colorless. Found with garnet in an ore deposit. Very rare.

Grothite (*grothine*) is probably related to harstigite; it is a silicate of Ca and Al with a little Fe. It is orthorhombic with $a : b : c = 0.458 : 1 : 0.848$. G. = 3.09. F. = 7. Attacked by H_2SO_4. Optic plane is 001; X = b. (+) 2V = medium, $\rho < v$. $N_m = 1.554$, $N_g - N_m = 0.016$. Colorless. Found in a contact zone. Very rare.

Orientite [17] ($4CaO \cdot 2Mn_2O_3 \cdot 5SiO_2 \cdot 4H_2O$) is orthorhombic with $a : b : c = 0.672 : 1 : 0.792$. Crystals prismatic or 010 tablets with imperfect 110 cleavage. H. = 4.5–5. G. = 3.05. F. = difficult. Soluble in HCl. Optic plane is 001; X = a. (+) 2V = 67°, $\rho < v$ very strong. $N_g = 1.795$, $N_m = 1.776$, $N_p = 1.758$, $N_g - N_p = 0.037$. Color dark brown with X = red brown, Y = yellow, Z = brownish yellow and X > Z > Y. Found in ore deposits in Cuba. Very rare.

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[17] D. F. Hewett and E. V. Shannon: *Am. Jour. Sci.*, CCI, 1921, p. 491.

Zebedassite $\{H_8Mg_5Al_2(SiO_4)_6\}$ is probably orthorhombic; fibrous. H. = 2. G. = 2.19. F. = 7. Gelatinizes with acid. $Z = c$; therefore extinction is parallel and elongation is positive. $N_m = 1.52 \pm$, $N_g - N_p$ = strong. Color white. Found as a vein mineral in Italy. Very rare.

Pumpellyite [18] $(6CaO \cdot 3Al_2O_3 \cdot 7SiO_2 \cdot 4H_2O)$ is orthorhombic and fibrous or in 001 tablets with perfect 001 cleavage. H. = 5.5. G. = 3.2. Insoluble in HCl. If the fibers are parallel to b the optic plane is 010 and $X = c$. (+) 2V = rather large, $\rho < v$ very strong. $N_g = 1.708$, $N_m = 1.700$, $N_p = 1.698$, $N_g - N_p = 0.010$. Color bluish green with X and Z = colorless, Y = green. Common in Lake Superior copper ores.

EUCLASITE (*Euclase*) MONO. $a : b : c = 0.324 : 1 : 0.333$ $\beta = 79° 44'$ $HBeAlSiO_5$

PHYS. CHAR.—Crystals prismatic with many faces. Perfect 010 and difficult 110 and 001 cleavages. Slight vertical elongation. H. = 7.5. G. = 3.0–3.1. F. = 5.5. Insoluble.

OPT. PROP.—The optic plane [19] is 010; $Z \wedge c = +41°$. (+) $2V = 50° \pm$, $\rho > v$. $N_g = 1.671$, $N_m = 1.655$, $N_p = 1.651$, $N_g - N_p = 0.020$. $N_g - N_p = 0.0153$ [20]. Colorless, pale green or blue; may be colored and pleochroic in thick plates, with variable orientation of colors.

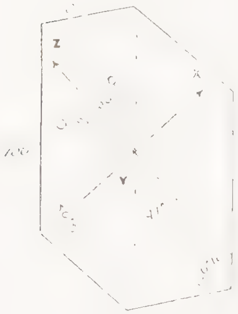

FIG. 288.—Optic orientation of euclasite.

OCCUR.—In chlorite schists with topaz, etc. Rare.

DIAG.—Crystal form, perfect cleavage, positive elongation with very large extinction angle, high relief and association with topaz are distinctive, as well as the presence of beryllium.

Lotrite $\{3(Ca,Mg)O \cdot 2(Al,Fe)_2O_3 \cdot 4SiO_2 \cdot 2H_2O?\}$ is massive, probably monoclinic, with perfect cleavage parallel to elongation. H. = 7.5. G. = 3.23. Optic plane normal to cleavage and across elongation with extinction at 28° to cleavage trace. (+) $2V = 18° \pm$, $N_m = 1.67$, $N_g - N_p = 0.014$. Color green in mass. Found in veins in schist. Very rare.

Racewinite [21] $(CaO \cdot 5Al_2O_3 \cdot 12SiO_2 \cdot 20H_2O?)$ is massive with conchoidal fracture and no cleavage. H. = 2.5. G. = 1.94–1.98. (−) 2V = large, $N_m = 1.51 \pm$, $N_g - N_p = 0.01 \pm$. Color of the fresh mineral in place underground is bluish green, changing slowly to yellow-brown to dark brown; in nitric acid the color becomes lighter brown; fragments which have been in nitric acid change color in clove oil to green. Found near porphyry in limestone at Bingham, Utah.

EPIDOTE GROUP

The epidote group includes several silicates of aluminum, calcium and hydrogen with more or less iron, manganese, cerium, etc. The chief molecule $(HCa_2Al_3Si_3O_{13})$ is dimorphous, but only monoclinic forms are known for the remaining members of the group, which may be classified as follows:

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[18] C. Palache and H. E. Vassar: *Am. Mineral.*, X, 1925, p. 412.

[19] L. Weber: *Tables Ann. Intern. Const.*, V., 1925.

[20] H. Buttgenbach: *Bull. Acad. Roy. Belg. Cl. Sci.*, 1924, p. 456.

[21] A. N. Winchell: *Econ. Geol.*, XIII, 1918, p. 611

Zoisite	$HCa_2Al_3Si_3O_{13}$	Orthorhombic
Clinozoisite	$HCa_2Al_3Si_3O_{13}$	Monoclinic
Pistacite (or common epidote)	$HCa_2(Al,Fe''')_3Si_3O_{13}$	Monoclinic
Piedmontite	$HCa_2(Al,Mn''')_3Si_3O_{13}$	Monoclinic
Hancockite	$HCa(Pb,Sr)(Al,Fe''',Mn''')_3Si_3O_{13}$	Monoclinic
Allanite	$HCaFe''(Al,Ce,Fe''')_3Si_3O_{13}$	Monoclinic

The relation in form between zoisite and epidote can be made apparent by exchanging for zoisite c and b and also b and a, when the axial elements become:

$$\text{Zoisite } a : b : c = 1.458 : 1 : 1.790$$
$$\text{Epidote } a : b : c = 1.579 : 1 : 1.804$$

The relative orientation is reasonable since it makes the perfect cleavage of zoisite parallel to the base, as it is in epidote; further, the zone of elongation and striation in both minerals is then parallel to the b axis. The ratios for a may be made nearly identical by taking $\bar{1}01$ of epidote as 001.

ZOISITE ORTH. $a : b : c = 0.620 : 1 : 0.343$ $HCa_2Al_3Si_3O_{13}$

COMP.—A little ferric iron (to about 5 per cent Fe_2O_3) is not unknown in zoisite, but its presence seems to favor crystallization in the monoclinic form.

PHYS. CHAR.—Crystals prismatic deeply striated vertically; massive. Perfect 010 cleavage. H. = 6. G. = 3.25–3.36. F. = 3 with swelling. Insoluble.

OPT. PROP.—Iron-free zoisite[22] (called *α-zoisite* by Termier)[23] has the optic plane parallel to 010 (= the cleavage) and the axis Z normal to 100, while zoisite with about 5 per cent Fe_2O_3 (about 10 molecular per cent iron-epidote, $HCa_2Fe_3Si_3O_{13}$) has the optic plane parallel to 001 (normal to the cleavage) and Z still normal to 100. Iron-free zoisite has (+) $2V = 30°\pm$, $\rho < v$, strong, while zoisite with about 5 per cent Fe_2O_3 (called *β-zoisite* by Termier) has (+) $2V = 60° \pm$, $\rho > v$, distinct. The optic angle passes through 0° between these two cases; when $2V = 0°$ for red, sections parallel to 100 (normal to Z) give abnormal blue interference colors; when $2V = 0°$ for blue (more Fe_2O_3 present), similar sections give a yellowish gray interference color. Zoisite may show distinct variations in these properties in a single crystal, probably due to differing tenor of Fe_2O_3 in zones of growth. The birefringence and probably the refringence increase with the tenor of Fe_2O_3, but precise data are lacking. $N_g = 1.702$–1.706, $N_m = 1.696$–1.702, $N_p = 1.696$–1.700, $N_g - N_p = 0.005$–0.009. With[24] $Fe_2O_3 = 2.14$: $N_g = 1.718$, $N_m = 1.703$, $N_p = 1.700$, $N_g - N_p = 0.018$.

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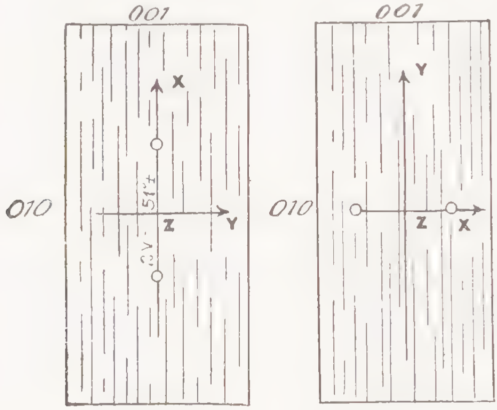
[22] F. Becke in Doelter: *Handb. Mineralch.*, II, 1, 1914, p. 23.

[23] *Bull. Soc. Fr. Min.*, XXI, 1898, p. 148 and XXIII, 1901, p. 50.



FIGS. 289, 290.—Optic orientation of iron-free or α-zoisite and ferriferous or β-zoisite.

Color gray, greenish, brown, green; colorless in thin section. The pink manganiferous variety called *thulite* is pleochroic in thin section with X = dark pink, Y = bright pink, Z = yellow.

OCCUR.—In schists often associated with amphibole. In igneous rocks as an alteration product of plagioclase. *Saussurite* is a feldspar mass more or less completely altered to a mixture of zoisite, new feldspars, actinolite, chlorite, etc. Zoisite is also found in quartz veins in altered basic igneous rocks. Zoisite is much less common than clinozoisite; the iron-free type is more abundant than the ferriferous mineral, which has the optic plane normal to the cleavage.

DIAG.—Distinguished in thin section by elongated sections with parallel extinction, high relief, very weak birefringence and (often) very strong dispersion. The elongation is negative, or, rarely, plus or minus. Differs from epidote in absence of color and much weaker birefringence, and from clinozoisite in having parallel extinction and smaller optic angle.

CLINOZOISITE MONO. $a:b:c = 1.583:1:1.814$ $HCa_2Al_3Si_3O_{13}$ $\beta = 64° 30'$

COMP.—There is a continuous series from the formula given to about 40 molecular per cent of $HCa_2Fe_3Si_3O_{13}$; clinozoisite is the name for types which are optically positive (less than 10 per cent $HCa_2Fe_3Si_3O_{13}$); the rest of the series is called pistacite or common epidote. See Fig. 288.

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[24] E. V. Shannon: *U. S. Nat. Mus. Bull.* 131, 1926, p. 323.

PHYS. CHAR.—Crystals 100 tablets elongated parallel to *b* with striations parallel to *b*. Perfect 001 cleavage. H. = 6.5. G. = 3.35–3.38. F. = 3 with swelling. Insoluble.

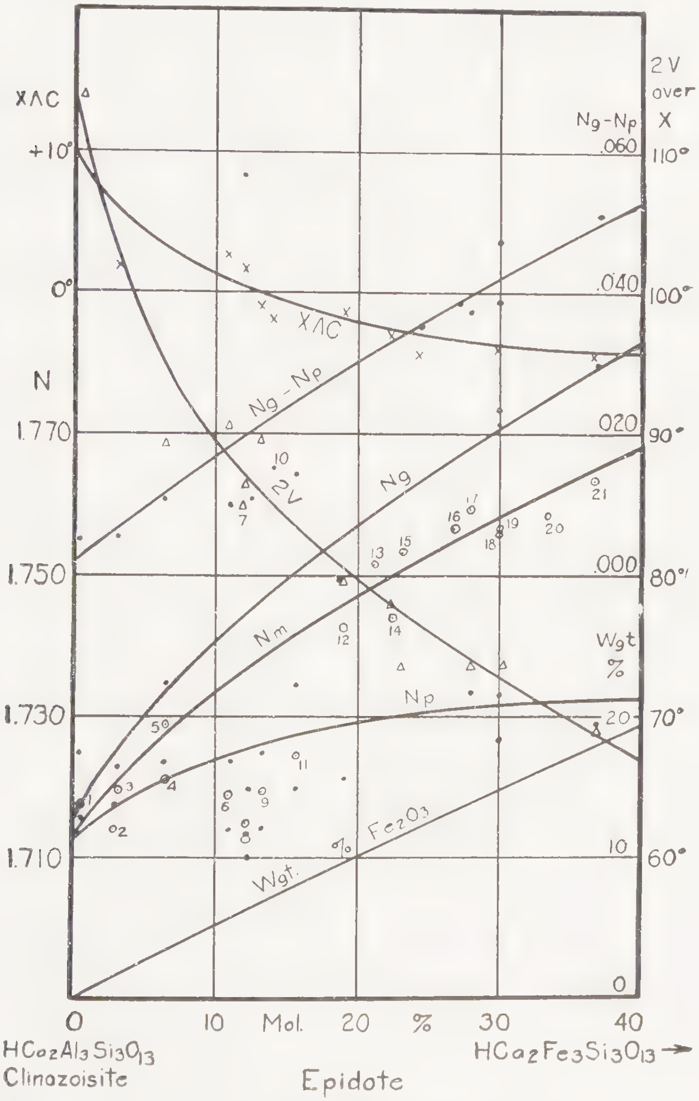

FIG. 291.—Variations in composition and optic properties in the epidote series.

OPT. PROP.—The optic plane is parallel to 010; the obtuse bisectrix X makes an angle of − 2° to − 12° with *c* (therefore, Z to 001 cleavage = 24° to 14°). The indices, birefringence and optic angle vary rapidly with the tenor or Fe_2O_3. See Fig. 291. With about 3 per cent Fe_2O_3:

$$(+)\ 2V = 85°,\ \rho < v$$

$$N_g = 1.734,\ N_m = 1.729,\ N_p = 1.724,\ N_g - N_p = 0.010.$$

Colorless, yellowish, greenish, pink; colorless in thin section; in thick sections pleochroic with X = greenish, Y = pink, greenish, Z = deep red, green.

Inver.—The stability relations between zoisite and clinozoisite are still unknown; pressure may be important.

Occur.—See zoisite.

Diag.—Differs from zoisite in inclined extinction in 010 measured on the cleavage and a very large optic angle; differs from pistacite in weaker birefringence.

PISTACITE (*Common epidote*) Monoclinic $HCa_2(Al,Fe)_3Si_3O_{13}$

$$a : b : c = 1.580 : 1 : 1.806 \quad \beta = 64°\ 36'$$

Comp.—Pistacite includes types with 10–40 molecular per cent of $HCa_2Fe_3Si_3O_{13}$; types with less iron are called clinozoisite; more iron is unknown in epidote.

Phys. Char.—Crystals nearly always elongated parallel to *b* with striations in the same direction; also granular. Twinning on 100 often lamellar. Perfect 001 and indistinct 100 cleavages.

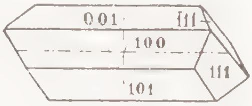

Fig. 292.—A crystal habit of epidote.

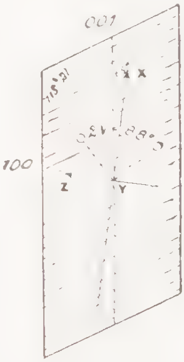

Fig. 293.—Optic orientation of epidote.

H. = 6–7. G. = 3.37–3.5. F. = 3 with intumescence. Partly decomposed by HCl.

Opt. Prop.—The plane of the optic axes is parallel with 010; the acute bisectrix X makes an angle of about 0° to 5° with *c* (therefore Z to 001 cleavage = 25° to 30°). The indices, birefringence and optic angle vary rapidly with the tenor of Fe_2O_3. See Fig. 291. Such variations are even common in a single crystal. Inclined dispersion strong with $\rho < v$ in one optic axis, $\rho > v$ in the other optic axis, and $\rho > v$ for $X \wedge c$. Data follow:

	Anderson[25]	Weinschenk[26]	Goldschlag[27]
% Fe_2O_3 =	12.0	14.3	17.3
(−) 2V =	73° 39′	......	68° 53′
N_g =	......	1.771	1.780
N_m =	1.753	1.759	1.763
N_p =	......	1.734	1.729
$N_g - N_p$ =	0.033	0.037	0.051
G. =	3.386	......	3.554

$N_m - N'_p$ on the 001 cleavage[28] = 0.002 to 0.010.

Color green (usually yellowish), also yellow or gray. In thin section pale yellow to orange with $Y > Z > X$ and in

	Sections .03 mm. thick	Thick sections
X =	colorless, lemon yellow, pale green	green
Y =	greenish yellow, pale blue	brown
Z =	colorless, yellowish green, pink	green

By looking through a basal plate of epidote at a clear sky, absorption figures may be seen, somewhat resembling interference figures. They are called *houppes* or *epoptic figures*, and are shown only by minerals of strong absorption when observed along an optic axis; they are areas of color shaped about like the concave areas of the isogyres of an acute bisectrix interference figure of small optic angle at the 45° position. In epidote they are brown spots on a green field. Such figures are shown also by andalusite, cordierite, tourmaline, and a few other minerals.

ALTER.—Epidote is stable at ordinary temperature and alteration products due to katamorphism are rare. Anorthite and augite or meionite often with magnetite result when epidote is fused and recrystallized.

OCCUR.—Epidote is very common, especially in contact zones and schists. It is also abundant as an alteration product (probably under hydrothermal conditions) of ferromagnesian minerals and feldspars.

DIAG.—The high refringence, parallel extinction in longitudinal sections, inclined extinction in transverse sections, and strong birefringence, variable in a single crystal, are quite characteristic. The forms, color and pleochroism are also distinctive. Unlike augite, sections showing one cleavage and small or 0° extinction angles have the optic plane normal to the cleavage.

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[25] *Archiv. Math. Naturvid.*, XXXI, 1911, No. 15; through *Zeit. Kryst.*, LVII, 1922, p. 322.

[26] *Zeit. Kryst.*, LVII, 1922, p. 322.

[27] *Tsch. Min. Pet. Mitth.*, XXXIV, 1917, p. 23.

[28] H. Buttgenbach: *Minéraux et Roches*, 1916, p. 510.

PIEDMONTITE MONO. $a : b : c = 1.559 : 1 : 1.778$ $\beta = 64° 39'$ $HCa_2(Al,Mn)_3Si_3O_{13}$

PHYS. CHAR.—Crystals like epidote, with perfect 001 cleavage and twinning on 100. H. = 6.5. G. = 3.4-3.5. F. = 3, with intumescence. Insoluble.

OPT. PROP.—The optic plane is 010; $X \wedge c = -7° \pm$, therefore Z to 001 cleavage = 32° ±. (+) 2V = 80° to 55°, inclined dispersion with $\rho > v$ strong. $N_g = 1.75 \pm$ to $1.82 \pm$, $N_m = 1.73$ to 1.77, $N_p = 1.74$ to 1.76, $N_g - N_p = 0.03$ to $0.048 \pm$. There is probably a series from clinozoisite to about 40 mol. per cent $HCa_2Mn_3Si_3O_{13}$, as in epidote, but details are lacking.

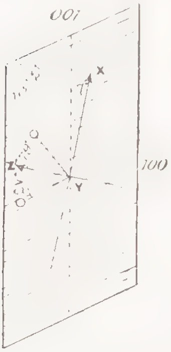

FIG. 294.—Optic orientation of piedmontite.

Color reddish brown to black; in thin section X = lemon to orange yellow, Y = amethyst, violet, pink, Z = bright red, and X > Y > Z.

OCCUR.—In schists and gneisses; also in rhyolite. Rare.

DIAG.—Differs from epidote in color, pleochroism, positive bisectrix and manganese reactions.

Hancockite $\{HCa(Pb,Sr)(Al,Fe)_3Si_3O_{13}\}$ is monoclinic; crystals like epidote. Perfect 001 cleavage. H. = 6-7. G. = 4. F. = 3, with intumescence. Insoluble in HCl. The optic plane is 010; extinction angle unknown. (−) 2V = 50° ±, $\rho > v$, $N_g = 1.830$, $N_m = 1.81$, $N_p = 1.788$, $N_g - N_p = 0.042$. Color brownish red; in fragments X or Z = rose or greenish yellow, Y = yellowish brown, with absorption Z > X. Found at Franklin, N. J., with garnet and axinite. Very rare.

ALLANITE (*Orthite*) MONOCLINIC $HCaFe''(Al,Ce,Fe''')_3Si_3O_{13}$
$a : b : c = 1.551 : 1 : 1.768$ $\beta = 64° 59'$

PHYS. CHAR.—Crystals 100 tablets or acicular parallel to *b*; massive. Cleavages not distinct. H. = 6. G. = 4.15 (to 2.7, altered). F. = 2.5, with swelling. Gelatinizes with HCl.

OPT. PROP.—The optic properties vary decidedly in different cases, doubtless with variations in composition, but precise data are lacking. In many cases the optic plane is 010 and $X \wedge c = 30$ to 40° approx. (also given as "very small" by Lacroix). In other cases the optic plane is normal to 010 and $X \wedge c = 22°$ to 41

(−) 2V = large, $\rho > v$ (also +?). $N_g = 1.66 \pm$ to $1.80 \pm$, $N_m = 1.65$ to $1.78 +$, $N_p = 1.64 \pm$ to $1.77 \pm$, $N_g - N_p$ = weak to 0.032 (commonly 0.01 to 0.02).

Pleochroic in section with X = colorless, Y = ?, Z = pale green.

By alteration (or inversion?) allanite becomes isotropic and the refringence[29] decreases to N = 1.53 to 1.70. As the specific gravity decreases from 3.5 to 3.2 the index decreases from 1.70 to 1.64. According to Larsen, the process may be reversed, an isotropic mineral becoming anisotropic, apparently by alteration. The secondary mineral has (−) 2V = rather large, $\rho > v$ distinct, $X \wedge c = -17°$ to $-25°$, $N_m = 1.71$ to 1.76, $N_g - N_p = 0.01$

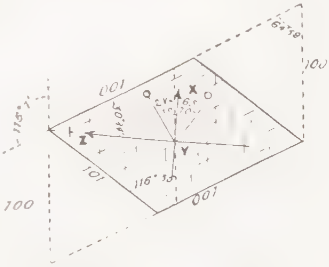

FIG. 295.—Optic orientation of allanite.

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[29] N. Zenzen: *Bull. Geol. Inst. Univ. Upsala*, XV, 1915, p. 61.

to 0.02; it is pleochroic in red-brown with Y and $Z > X$, the primary mineral being either isotropic or pleochroic in green and yellow.

Ordinary allanite is heterogeneous, but usually composed of this secondary substance in large part. It is brown to black in mass and isotropic or strongly pleochroic with X = yellow (to brown), Y = dark brown, Z = dark reddish brown.

Allanite may produce intense pleochroic halos in biotite.

It may be surrounded by epidote of similar crystal orientation, but somewhat different extinction position.

OCCUR.—An uncommon accessory constituent of igneous rocks, especially the acid types. Also in gneiss, schists, and magnetite iron ores.

DIAG.—The high refringence, varying color and properties (even in a single crystal), pleochroism in brown (and green), great variations in birefringence, and common association with epidote are distinguishing features.

Magnesium orthite [30] contains up to about 35 per cent of $HCaMgMg_3Si_3O_{10}F_3$ (as well as Mg for Fe″ in the orthite formula). It has $G. = 3.90$; $(+)\ 2V = 50° \pm$, $N_g = 1.733$, $N_m = 1.718$, $N_p = 1.715$, $N_g - N_p = 0.018$. Weakly pleochroic pinkish to brown. There is probably a gradation from orthite to this substance. Very rare.

MICA GROUP

The mica group includes silicates of aluminum and potassium, usually with magnesium, iron or lithium as well as hydroxyl or fluorine. The members of the group are monoclinic and pseudohexagonal with perfect basal cleavage giving thin elastic laminæ; they are characterized by weak birefringence in cleavage flakes and basal sections combined with strong birefringence in transverse sections.

PHYS. CHAR.—Crystals of all the micas, when developed under the most favorable conditions for free growth, as in pegmatites, are pseudohexagonal prismatic with distinct vertical elongation; but such conditions are rare and the usual crystals are thin basal plates of hexagonal outline; in all of them the angle β is very near 90° and the prism angles (110 to $1\bar{1}0$ and 110 to 010) are very near 60°. A blow with a dull point on a cleavage plate of any mica develops a six-rayed "percussion figure," one line being more distinct than the other two (see Fig. 296). This line is parallel to 010, while the others are parallel to the prism faces. The percussion figure makes it possible to determine the position of 010 (and hence the optic orientation) in any cleavage piece of mica, even though no crystal faces are present. Pressure instead of a blow, on the basal plane of mica, produces a six-rayed "pressure figure" whose lines are perpendicular to those of the percussion figure.

Twinning is common, the twinning plane being 110 and the composition face 001 or 110. Ferromagnesian micas are attacked by

[30] P. Geijer: *Sver. Geol. Unders. Aarsb.*, 20, No. 4, 1927.

acids leaving a skeleton of silica; other micas are nearly or quite insoluble. H. = 2.5–4. G. = 2.75–3.2. F. = 2–6.

Opt. Prop.—The negative acute bisectrix is sensibly or nearly normal to the basal cleavage so that cleavage flakes give a (nearly) centered bisectrix interference figure. The optic angle (2V) is very small to 0° in biotite and not very large (45° ±) in muscovite. The optic plane is normal to 010 in muscovite and parallel thereto in biotite; the percussion figure is useful in obtaining the optic orientation.

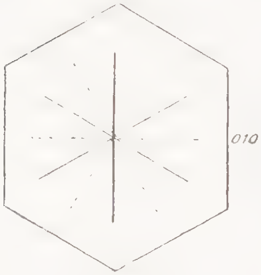

Fig. 296.—Percussion figure (in full lines) and pressure figure (in dotted lines) in mica.

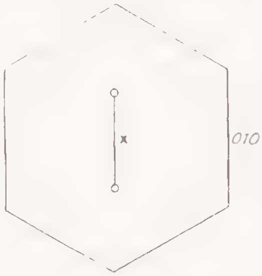

Fig. 297.—Optic orientation of the octophyllite micas.

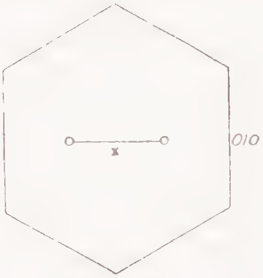

Fig. 298.—Optic orientation of the heptaphyllite micas.

The refringence is low in lepidolite and phlogopite and always distinct in other micas; the birefringence is strong in all micas. Absorption is very strong in colored micas with maximum parallel to the cleavage. The color varies from gray to yellow, brown, green, black, pink and violet in different types.

Diag.—In thin section micas are characterized by distinct relief (except lepidolite and phlogopite), strong birefringence, acute bisectrix of small optic angle normal to the single cleavage which is marked by fine parallel lines, sensibly (or nearly) parallel extinction, a mottled appearance between crossed nicols, and strong absorption (in colored micas) parallel to the cleavages.

Class.—There is no agreement regarding the interpretation of analyses of micas, and therefore regarding their classification, except as to the formulas of muscovite and phlogopite. In the following paragraphs the interpretation of the author is given; other recent studies of the composition of the micas include those of Kunitz[30a]

[30a] *N. Jahrb. Min. Beil. Bd.*, L, 1924, p. 365.

and of Hallimond.[30b] The writer's classification[31] of the micas is as follows:

I. Heptaphyllite			
	A. Muscovite System	Muscovite	$H_4K_2(Al,Fe)_6Si_6O_{24}$
		Phengite	$H_4K_2(Mg,Fe)Al_4Si_7O_{24}$
	B. Lepidolite System	Lepidolite	$H_4K_2Li_2Al_4Si_6O_{22}$
		Polylithionite	$H_8K_2Li_4Al_2Si_6O_{22}$?
		Protolithionite	$H_4K_2Fe''_3Al_4Si_5O_{22}$
		Cryophyllite	$H_4K_2Li_2FeAl_2Si_7O_{22}$?
II. Octophyllite			
	C. Biotite System	Phlogopite	$H_4K_2Mg_6Al_2Si_6O_{24}$
		Eastonite	$H_4K_2Mg_5Al_4Si_5O_{24}$
		Siderophyllite	$H_4K_2Fe_5Al_4Si_5O_{24}$
		Annite	$H_4K_2Fe_6Al_2Si_6O_{24}$

THE HEPTAPHYLLITE MICAS

The heptaphyllite micas are characterized chemically by having seven (or fourteen) atoms in the formula (excluding O, H and F) and optically by having an optic angle (2V) usually of 30° to 50° with the optic plane normal[32] to 010 and dispersion $\rho > v$, except in Fe''-phengite and roscoelite.

MUSCOVITE SYSTEM

MUSCOVITE MONOCLINIC (PSEUDOHEX.) $H_4K_2(Al,Fe)_6Si_6O_{24}$
PHENGITE $a : b : c = 0.577 : 1 : 3.313$ $H_4K_2(Mg,Fe)Al_4Si_7O_{24}$
$\beta = 89° 54'$

PHYS. CHAR.—Crystals usually tabular with hexagonal outline; commonly lamellar massive. Perfect 001 cleavage yielding thin elastic laminæ; also secondary parting or slip planes parallel to 110 and 010. H. = 2.5–3. G. = 2.76–3. F. = 5.7 to gray or yellow glass. Insoluble in acids.

OPT. PROP.—The plane of the optic axes is normal to 010 and sensibly normal to 001; the negative acute bisectrix X makes an angle of 0° (to 2°) with a normal to 001. The optic angle (2V) is about 45° for iron-free muscovite; the dispersion is distinct with $\rho < v$. The relief is distinct (with lowered condenser or inclined illumination) and the birefringence is very strong. As shown in Fig. 299, the mean index (and birefringence?) increases rapidly with increase of ferric iron while the optic angle decreases steadily with increase in the tenor of phengite.

[30b] *Mineral Mag.*, XX, 1925, p. 305, and XXI, 1926, pp. 25 and 195.

[31] A. N. Winchell: *Am. Jour. Sci.*, CCIX, 1925, pp. 309 and 415, and *Am. Mineral.*, XIII, July, 1927.

[32] The contrary position has been reported in lepidolite (for example, by Schaller: *U. S. Geol. Surv. Bull.* 262, 1905, p. 144); such a condition may be due to a variable, such as hydroxyl-fluorine, not used in the diagram, or to inversion, as suggested by Bowman's report (*Mineral. Mag.*, XIII, 1893, p. 103) that such lepidolite is monoclinic while ordinary lepidolite is triclinic.

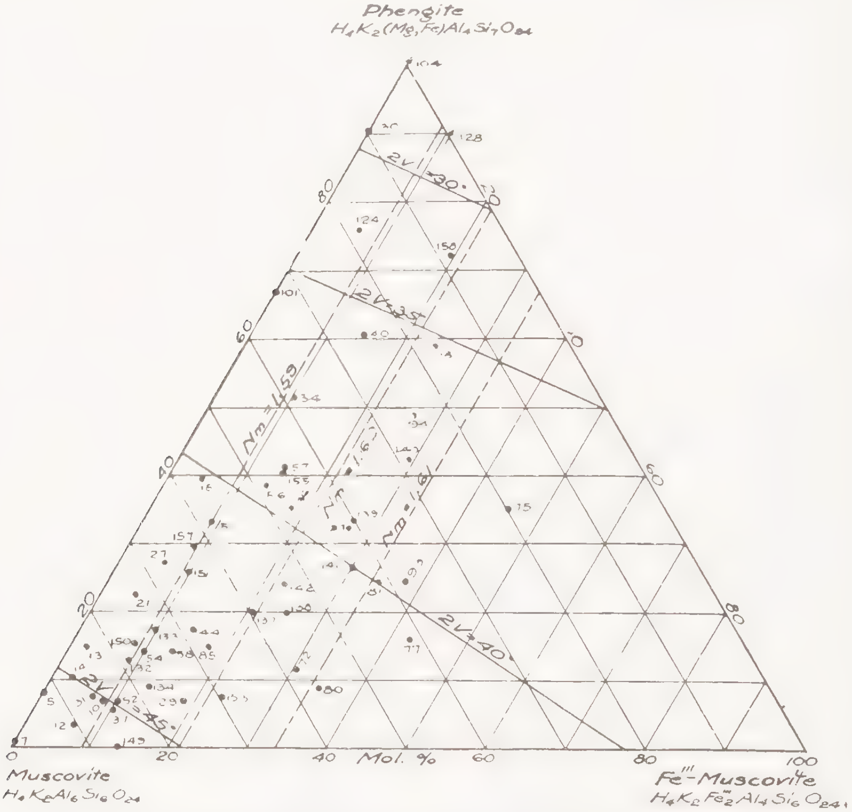

FIG. 299.—Variations in composition and optic properties in the muscovite system.

Data for muscovite and extrapolated properties for phengite are:

	Pure Muscovite	Mg-Phengite	Fe''-Phengite
(−) 2V =	47°	25° ±	10° +
Optic Plane	⊥ 010	⊥ 010	∥ 010
N_g =	1.588		
N_m =	1.582	1.59 ±	1.61 ±
N_p =	1.552		
$N_g - N_p$ =	0.036	0.04 ±	0.04 ±

Colorless, gray, brown, pale green, etc. Luster vitreous to pearly. Streak colorless. In thin section colorless, except in some pleochroic halos, which are found only in types containing an appreciable tenor of iron. Such types are pleochroic in thick sections and halos, with $X < Y = Z$ and $X =$ colorless, $Y = Z =$ pale yellow to brown.

INCL.—Zircon crystals are sometimes found as inclusions; they may produce pleochroic halos even in otherwise colorless muscovite. Other minerals sometimes present include apatite, spinel, garnet, tourmaline, quartz, and magnetite or hematite, the last in dendritic forms.

ALTER.—By hydration muscovite alters to *damourite,* or " hydromica "; by leaching, which removes the potash, it may alter to kaolinite, or gibbsite with quartz, or antigorite or talc with gibbsite.

OCCUR.—Muscovite is the most common of the micas. It is a normal constituent of many igneous rocks, especially granites. It is an important constituent of gneiss, micaschist, and related rocks. It occurs in large crystals in veins and pegmatites. It is a secondary mineral in many cases, being derived from feldspar, nephelite, scapolite, spodumenite, cordierite, cyanite, topaz, etc. It occurs sparingly in sedimentary rocks like shales, but anamorphism of such materials frequently causes its development.

DIAG.—Muscovite differs from pale phlogopite in the position of the optic plane, from talc in its larger optic angle (in most cases), and from kaolinite, chlorite, etc., in its strong birefringence. It differs from micas of the lepidolite system in having higher indices of refraction for equal values of the optic angle, as shown on Figs. 299 and 300.

Damourite is an altered muscovite containing more water or more easily removed water. The cleavage laminæ are flexible, but lose their elasticity as the change progresses. Also the optic angle decreases nearly to zero.

Sericite is a fine scaly or fibrous kind of muscovite; the name is usually confined to white mica which is secondary. It is often the product of alteration of feldspar. Recent data[33] suggest that it contains less potash and more water and has a smaller optic angle than ordinary muscovite.

Fuchsite is a variety of muscovite containing Cr_2O_3 replacing part of the Al_2O_3. (−) $2E = 68°–70°$, $\rho > v$ distinct, $N_m = 1.595$, $N_g - N_p =$ very strong, as in muscovite. Nearly colorless in section, but in thick section $X =$ colorless to pale greenish blue, Y = yellowish green, Z = dark bluish green. Found in micaceous quartzites and mica schists, and sparingly in some gneisses and dolomites.

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[33] E. V. Shannon: *U. S. Nat. Mus. Bull.* 131, 1926, p. 367.

Chromocre is similar, but has more Cr_2O_3 and a very small optic angle; it may be a chromiferous phengite.

Paragonite ($H_4Na_2Al_6Si_6O_{24}$) is the name given to a supposed sodium mica. It has been described as having (−) 2V = 40° ± (Larsen[34]), 0° (Johnsen[35]), $N_m = 1.60$, $N_g - N_p = .03$ (Larsen), and X very nearly normal to 001. However, there is no conclusive evidence that such a mineral exists, although it has been reported in massive condition in some schists.

Roscoelite is a vanadium-rich muscovite. A sample from the Stockslager mine[36] has $V_2O_3 : Al_2O_3 = 160 : 113$ and about 55 per cent phengite. A sample from the same mine[37] has perfect 001 and distinct 010 cleavages with H. = 2.5, G. = 2.97, optic plane normal to 010, X nearly normal to 001, (−) 2E = 42° to 80° Na, $\rho < v$ distinct, $N_g = 1.692–1.704$, $N_m = 1.682–1.685$, $N_p = 1.615–1.610$, $N_g - N_p = 0.077–0.094$. Color clove brown to olive green with X = Y = olive green, Z = green-brown and $X < Y < Z$. Abnormal applegreen interference colors on cleavage pieces are characteristic. Associated with gold ores in California and Colorado. Rare.

LEPIDOLITE SYSTEM

LEPIDOLITE	MONOCLINIC (*or* TRICLINIC)	$H_4K_2Li_2Al_4Si_6O_{22}$
POLYLITHIONITE	(PSEUDOHEXAGONAL)	$H_8K_2Li_4Al_2Si_6O_{22}$?
PROTOLITHIONITE		$H_4K_2Fe_3Al_4Si_5O_{22}$

COMP.—The formulas of the end members of this system are still under discussion. *Cryophyllite* ($H_4K_2Li_2FeAl_2Si_7O_{22}$?) seems to be another end member molecule. Ordinary lepidolite contains up to about 50 per cent of the polylithionite molecule, the remainder being almost wholly the lepidolite molecule. *Zinnwaldite* is intermediate between ordinary lepidolite and protolithionite.

PHYS. CHAR.—Aggregates of short prisms or laminæ: fan-shaped or rosettes. Perfect 001 cleavage; twinning on 110 rather uncommon. H. = 2.5–4. G. = 2.8–3.3. F. = 1.5–2.5. More or less attacked by acids.

OPT. PROP.—The optic plane is normal[32] to 010 and the acute bisectrix is sensibly normal to 001; the optic angle (2V) varies from 50° to 0°; the relief is low to moderate and the birefringence strong. The optic properties vary with the composition as follows (as deduced chiefly from Fig. 300).

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[34] *U. S. Geol. Surv. Bull.* 679, p. 254; apparently based on Schr. v. d. Kolk: *Tabellen,* 1906, p. 38.

[35] *Cent. Mineral.*, 1908, p. 618, and 1911, p. 35.

[36] W. F. Hillebrand: *Am. Jour. Sci.*, VII, 1899, p. 451.

[37] F. E. Wright: *Am. Jour. Sci.*, XXXVII, 1914, p. 305.

	Ordinary lepidolite		Zinnwaldite	Protolithionite
	Lep_{100}	$Lep_{50}Poly_{50}$	$Lep_{33}Poly_{33}Prot_{33}$	$Prot_{100}$
(−) 2V =	52° ±	0° ±	35° ±	0° ±
N_g =	1.57 ±	1.555 ±	1.58 ±	1.63 ±
N_m =	1.56 ±	1.555 ±	1.57 ±	1.63 ±
N_p =	1.54 ±	1.53 ±	1.55 ±	1.59 ±
$N_g - N_p$ =	0.028 ±	0.025 ±	0.03 ±	0.04 ±

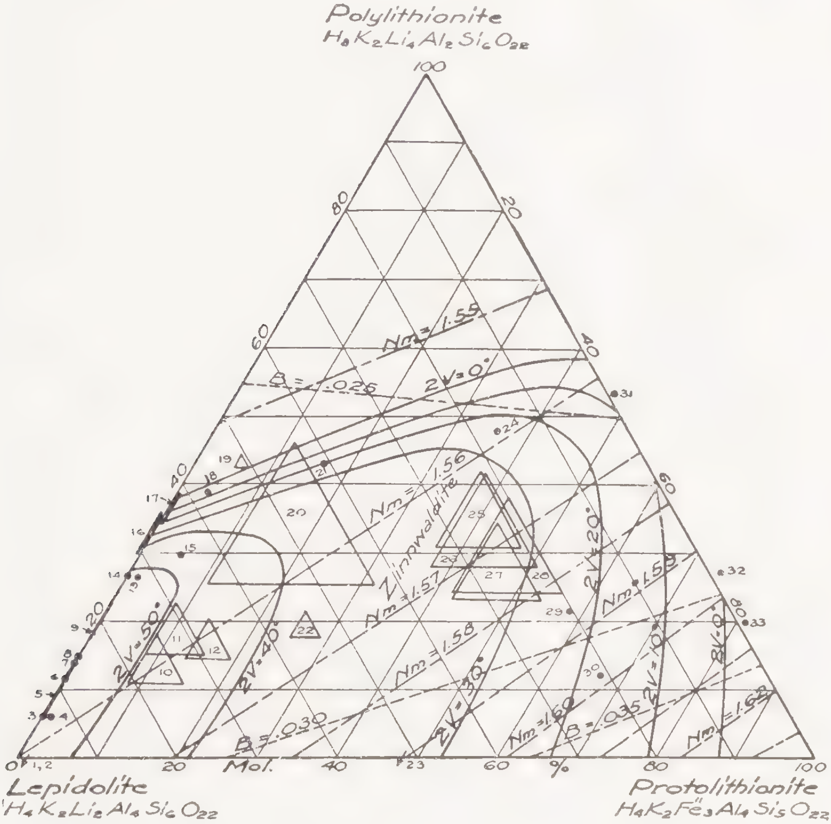

FIG. 300.—Variations in composition and optic properties in the lepidolite system.

The color of lepidolite is pink, red, violet, yellow, gray, white; that of zinnwaldite is violet, yellow, gray, brown; that of protolithionite is brown, greenish, black; the lighter colored types are colorless in thin section; others are pleochroic, as follows:

	Lepidolite	Zinnwaldite	Protolithionite	Cryophyllite
X =	colorless	yellowish, reddish	yellow	green
Y =	pink, violet	brownish gray, brown	brown	brownish red
Z =	pink, violet	brownish gray, brown	brown	brownish red

Inver.—Both lepidolite and zinnwaldite are reported as having the optic plane parallel to 010 (with $\rho < v$) in some cases. Such micas perhaps owe this condition to inversion, rather than to any chemical differences, since they are reported to differ in symmetry from the types with the optic plane normal to 010; the latter have in lepidolite[38] an extinction angle ($X \wedge c$) of 6°–7° in a plane normal to 010 and 001; in ordinary lepidolite $X \wedge c = 0°–7°$ in 010.

Incl.—Rutile, zircon, cassiterite and topaz are known as inclusions, usually surrounded by pleochroic halos.

Occur.—In veins and pegmatites with tin ores, topaz, tourmaline, etc. Commonly in parallel growths with muscovite.

Diag.—Differ from phlogopite and biotite in the position of the optic plane, and from muscovite in having lower refringence for equal values of the optic angle, as shown in Figs. 299 and 300.

Anomite is a name given to black mica which is unlike biotite in having the optic plane normal to 010. Perhaps some anomite is actually a variety of biotite, but the best analysis[39] yet made of so-called anomite belongs to the lepidolite system and contains about 60 molecular per cent of protolithionite. Anomite is like zinnwaldite in having an extinction angle usually reaching about 4° ($X \wedge c$). The optic angle is always small with dispersion $\rho > v$ ($\rho < v$ also reported). The color is always brown or reddish (never green) with X = yellow, Y and Z = brown to reddish brown, and $X < Y$ and Z.

THE OCTOPHYLLITE MICAS

The octophyllite micas are characterized chemically by having eight (or sixteen) atoms in the formula (excluding O, H and F) and optically by having an optic angle (2V) usually 0° to 5° with the optic plane parallel[39a] to 010 and dispersion $\rho < v$.

BIOTITE SYSTEM

PHLOGOPITE	Monoclinic	$H_4K_2Mg_6Al_2Si_6O_{24}$
EASTONITE	Pseudohexagonal	$H_4K_2Mg_5Al_4Si_5O_{24}$
SIDEROPHYLLITE	$a : b : c = 0.577 : 1 : 3.274$	$H_4K_2Fe_5Al_4Si_5O_{24}$
ANNITE	$\beta = 90° \pm$	$H_4K_2Fe_6Al_2Si_6O_{24}$

Phys. Char.—Crystals are monoclinic, but almost hexagonal; usually six-sided prisms; often massive lamellar. Perfect basal cleavage; also 010 and 111 parting, thus giving the percussion and pressure figures. Twinning on 110 in thin 001 laminæ. H. = 2.5–3. G. = 2.8–3.4. F. = 5. Decomposed by H_2SO_4 leaving silica in scales. May be bent or broken in rocks that have been under strain.

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[38] H. L. Bowman: *Mineral. Mag.*, XIII, 1903: H. Baumhauer: *N. Jahrb. Min.*, 1876, I.

[39] E. S. Simpson: *Geol. Surv. W. Austral. Bull.* 48, 1912, p. 95.

[39a] The contrary position is characteristic of anomite, which is commonly regarded as a variety of biotite, but the best analysis on record (E. S. Simpson: *Geol. Surv. W. Austral. Bull.* 48) clearly belongs to the heptaphyllite system.

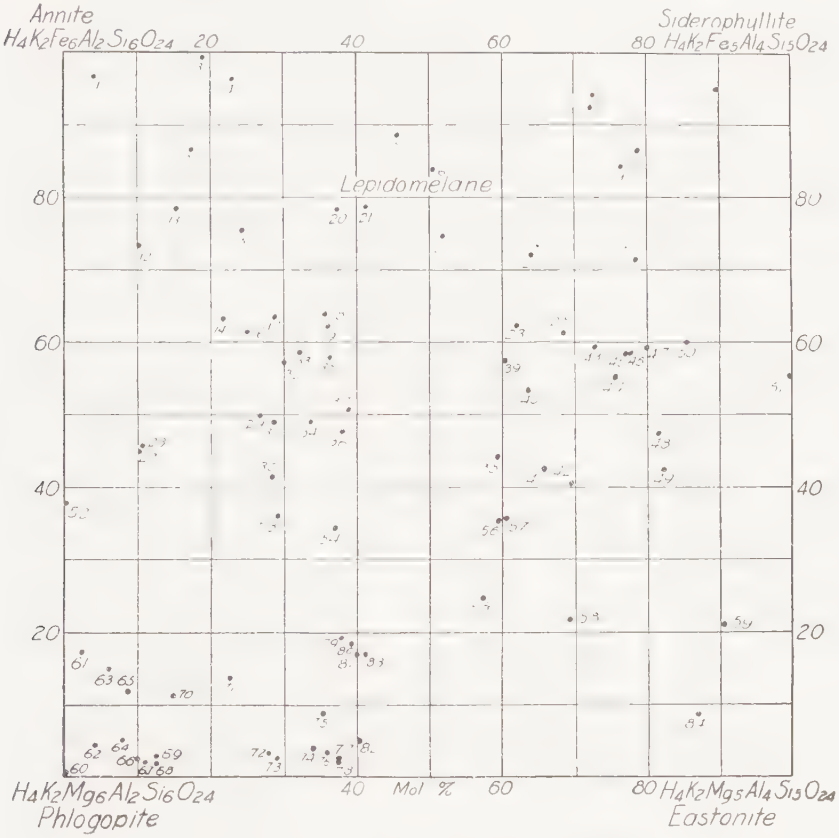

FIG. 301.—Variations in composition in the octophyllite micas.

OPT. PROP.—The plane of the optic axes is parallel [39a] to 010, and the acute bisectrix X is sensibly normal to 001. The relief is low to high and the birefringence very strong. The optic angle is practically zero in most biotite of igneous rocks, but may reach 70° for 2E in rare cases. The dispersion is weak with $\rho < v$. The optic properties vary with the composition as follows (as deduced chiefly from Fig. 302):

	Phlogopite	Eastonite	Siderophyllite	Annite
(−) 2V =	10°	Small	Small	Small
N_g =	1.565	1.578	1.670	1.690
N_m =	1.564	1.577	1.670	1.690
N_p =	1.535	1.542	1.616	1.630
$N_g - N_p$ =	0.030	0.036	0.054	0.060
G. =	2.75	2.86	3.19	3.35

The common types of biotite have 2V = 0°, or very nearly 0°, $N_g - N_m = 1.60$–1.66, $N_p = 1.56$-1.60, $N_g - N_p = 0.040$–0.060. In unusual types of biotite (probably containing ferric iron (and, or) titanium) N_g may reach 1.73[40]; for example, a biotite[40a] with 16.48 Fe_2O_3 and 24.06 FeO has $N_g = 1.697$, $N_m = ?$, $N_p = 1.616$, $N_g - N_p = 0.081$.

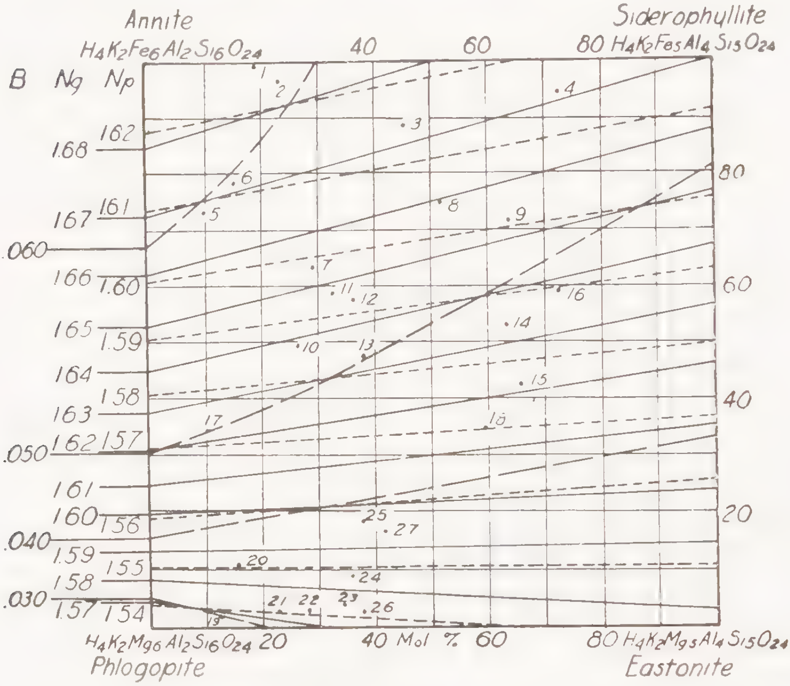

FIG. 302.—Relations of optic properties to composition in the octophyllite micas.

A very rare kind of mica recently found at Langban, Sweden[40b] seems to be a ferric iron equivalent of phlogopite; it has: (−) 2E = 22° 21′, $\rho > v$ strong, $N_g = 1.636$, $N_m = 1.636$, $N_p = 1.622$, $N_g - N_p = 0.014$, X = light and Z = dark red.

Color of the phlogopite-eastonite series is yellowish brown, reddish, greenish, yellow, colorless; usually pleochroic in thin section with X = colorless, Y = X = brownish yellow, and X < Y < Z. The color becomes darker with increase of iron, and the annite-siderophyllite series is black, green, brown or red; even with much less iron the color is very dark so that most biotite is deeply colored with marked pleochroism as follows:

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[40] C. S. Ross in F. C. Edson: *Okla. Geol. Surv. Bull.* 31, 1925, p. 15.

[40a] G. Schauberger: *Cont. Min.*, 1927, A, p. 103.

[40b] J. Jakob: *Zeit. Kryst.*, LXI, 1925, p. 155. A rare mica with 8.30 Mn_2O_3 is said to have X = dark brown and Z = light.

X = colorless	pure yellow	pure yellow	pale to dark yellow
Y = reddish brown	reddish brown	dark brown to opaque	grass green to opaque
Z = golden yellow	reddish brown	dark brown to opaque	grass green to opaque

Absorption usually $X < Y < Z$, but may be $X < Z < Y$. The ray vibrating parallel to the cleavage is always[40b] absorbed more than the ray vibrating normal thereto.

INCL.—Acicular inclusions are common in phlogopite; they cause asterism on account of their arrangement along lines crossing at about 60°. They are rutile, hematite, tourmaline, or an unknown mineral of low relief and strong birefringence. Pleochroic halos are more abundant about inclusions in biotite than in any other mineral. These inclusions may be zircon, apatite, or titanite, less commonly, allanite, rutile or liquids. The pleochroism in the halos is similar in color and position to that of the biotite, but it is more intense, so that the halo is often opaque parallel to Y and Z. The refringence and birefringence are greater in the halo than in other parts of the biotite. If the mica be heated to a high temperature without fusion the halos may disappear.

ALTER.—Biotite alters readily (probably under hydrothermal conditions) to chlorite, either directly, or by first changing from brown to green and then going to chlorite. The green mineral is considered still a mica since the birefringence is very strong, about as in the brown original. Epidote, calcite, quartz, rutile, octahedrite or brookite may be produced by alteration of biotite in place of, or with, chlorite.

Weathering of biotite usually changes it by loss of alkalies to a brown or golden yellow mineral with bronze luster. This substance has soft, flexible, inelastic laminæ; heated to 100° C., it loses water, and at a higher temperature it exfoliates and opens out into worm-like forms (hence the name *vermiculite*). It has strong birefringence like micas and unlike chlorites; the chemical composition is not well known, but seems to be variable; the mineral may belong with the leverrierite-stilpnomelanite system.

Under the influence of high temperature, biotite may suffer notable changes. The exterior may change without loss of form to magnetite, with or without augite, or it may recrystallize in part to biotite. In other cases it may change to hematite, to magnetite, spinel and hypersthene, with occasional sillimanite and recrystallized biotite.

Occur.—Phlogopite is rare in igneous rocks, but not so uncommon in exomorphosed dolomites. Eastonite (pure) is only hypothetical. Siderophyllite and annite are found in pegmatite. Biotite is an important constituent of many igneous rocks and of some metamorphic types such as gneiss and schist, where it may replace or accompany the muscovite. It is a product of both regional and contact metamorphism. It is not rare in sediments, though it may change to chlorite during katamorphism. *Lepidomelane* is any variety of biotite rich in iron; *meroxene* has been used as a name of " normal biotite "—that is, biotite with the optic plane parallel to 010; it might be better to apply it to biotites with magnesia dominant over iron oxide.

Diag.—Biotite differs from heptaphyllite chemically and also in the position of the optic plane, the small optic angle, and the dispersion; biotite is usually dark colored and pleochroic, while heptaphyllite is usually light colored or colorless, but these differences are not constant.

LEVERRIERITE—STILPNOMELANITE SYSTEM

The composition of minerals belonging to this system is not understood; they may be composed of the following hypothetical molecules in crystal solution in different proportions in various cases:

$$Al_2O_3 \cdot 5SiO_2 \cdot mH_2O\ (= A), \qquad 2Al_2O_3 \cdot 3SiO_2 \cdot mH_2O\ (= B),$$
$$4MgO \cdot 3SiO_2 \cdot mH_2O\ (= C), \qquad 4FeO \cdot 3SiO_2 \cdot mH_2O\ (= D),$$
$$Fe_2O_3 \cdot 5SiO_2 \cdot mH_2O\ (= E), \qquad 2Fe_2O_3 \cdot 3SiO_2 \cdot mH_2O\ (= F).$$

The name *leverrierite* has been applied especially to the series: A–B, though types are included containing notable amounts of the other molecules. *Pyrophyllite* and *montmorillonite* probably belong to the leverrierite system and are approximately $A_{80}B_{20}$, while *batchelorite* and *kryptotilite* are about $A_{20}B_{80}$. Montmorillonite is described on page 240 and pyrophyllite on page 238; in order to show its relationship to leverrierite, pyrophyllite is included, also, with leverrierite below. *Vermiculite* or *jefferisite* is about $C_{50}(B + D)_{50}$, *chalcodite* about $A_{40\pm}D_{60\pm}$, and *stilpnomelanite* about $(A + B)_{20}C_{30}(E + F)_{50}$. *Griffithite* may belong here also; it contains about 60 per cent of C.

LEVERRIERITE

MONOCLINIC (PSEUDOHEXAGONAL) $\left\{ \begin{array}{l} Al_2O_3 \cdot 5SiO_2 \cdot mH_2O \\ + n(2Al_2O_3 \cdot 3SiO_2 \cdot mH_2O)? \end{array} \right.$

PHYS. CHAR.—Vermicular aggregates with perfect 001 cleavage. H. = 1.5. G. = 2.5–2.6. F. = 5 ±, usually with swelling. Attacked by H_2SO_4.

OPT. PROP.—The optic plane is 010; X is sensibly normal to 001. (−) 2V = 0°–60°, N_g = 1.59–1.60, N_m nearly = N_g, N_p = 1.54–1.56, $N_g - N_p$ = 0.030–0.050.

	Pyrophyllite	Leverrierite	Kryptotilite
% A =	80	50 ±	20
% B =	20	50 ±	80
(−) 2V =	53°–62°, $\rho > v$, weak	0°	0°–45°
N_g =	1.600	1.602	1.594
N_m =	1.588	1.602	1.593
N_p =	1.552	1.558	1.558
$N_g - N_p$ =	0.048 (to 0.041)	0.044	0.036

Leverrierite is colorless, yellowish, greenish, brown; in section it is colorless or pleochroic with X = colorless, Y = dark brown, Z = clear brown, etc.

OCCUR.—Leverrierite is known in some schists, in gouge clays, and in sedimentary clays; it is abundant in "bentonite."

DIAG.—Differs from kaolinite in its strong birefringence; differs chemically from talc and muscovite, from which it is difficultly distinguished optically, though the indices are slightly higher than those of talc.

Vermiculite or **jefferisite** $\{4(Mg,Fe)O \cdot 3SiO_2 \cdot mH_2O + n(2Al_2O_3 \cdot 3SiO_2 \cdot mH_2O?)\}$ is lamellar with perfect 001 cleavage. H. = 1.5. G. = 2.4. Exfoliates. X normal to 001. (−) 2V = very small, $N_g = N_m$ = 1.58 to 1.59, N_p = 1.56 +, $N_g - N_p$ = 0.02±. N_m = 1.557 to 1.561 (Larsen). Color brown often with bronze yellow luster. Pleochroic with X = colorless, Y = Z = pale brown. A product of weathering of biotite; also in masses in Colorado. A nickeliferous vermiculite[41] from Webster Co., N. C., has N_g = 1.573, N_m = 1.573, N_p = 1.542, $N_g - N_p$ = 0.031. Color green with X = pale green, Y and Z = yellowish to brownish green.

Griffithite is closely related to jefferisite. It has X normal to 001, (−)2V = 0°-40°, N_g = 1.572, N_m = 1.569, N_p = 1.485, $N_g - N_p$ = 0.087. Color green with X = clear yellow, Y = olive green, Z = brownish green. Found in California. Rare.

Chalcodite (rich in FeO) is similar with X normal to 001. (−) 2V = very small, $N_g = N_m$ = 1.76 to 1.78, N_p = 1.63 to 1.65, $N_g - N_p$ = 0.13 ±. Also reported in isotropic condition. Color brown to black; strongly pleochroic with X = pale yellowish, Y = Z = dark red-brown. Found in iron ores with hematite and calcite.

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[41] C. S. Ross and E. V. Shannon: *Am. Mineral.*, XI, 1926, p. 90. Formula given as: $4(Mg,Ni)O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 6\frac{1}{2}H_2O$.

Stilpnomelanite[42] (rich in Fe_2O_3) is similar with X normal to 001. $(-)2V$ = very small, $N_g = N_m$ = (1.63 to) 1.69, N_p = 1.60 ±, $N_g - N_p$ = 0.09 ±; color brown to green, strongly pleochroic with X = yellowish, Y = Z = dark brownish green to dark brown. Found in iron ores with magnetite, quartz, etc.

An unnamed type found in iron ores in Minnesota is rich in both FeO and Fe_2O_3 and contains about 25 per cent of the phengite molecule. It has X normal to 001. $(-)\ 2V$ = very small, $N_g = N_m = 1.615$, $N_p = 1.546$, $N_g - N_p = 0.069$. Color brownish green; pleochroic. Found with quartz and carbonates, and also in slates.[43] A sample from Bohemia with 2.62 K_2O and 43. ± SiO_2 has $N_g = 1.677$, $N_p = 1.58$.

Cookeite ($Li_2Al_6Si_4O_{18} \cdot 6H_2O$?) is a micaceous mineral related to lepidolite in composition. Probably monoclinic with perfect 001 cleavage, the laminæ being flexible, but not elastic. H. = 2.5. G. = 2.67. F. = 6 with exfoliation. Attacked by H_2SO_4. Axis Z normal to cleavage. $(+)\ 2V$ = 0°–80°, $N_g = 1.597$, $N_m = 1.58$, $N_p = 1.576$, $N_g - N_p$ = about 0.021. A cleavage plate may be divided optically into six biaxial sectors with a uniaxial center.[44] A narrow border may have $N_m = 1.54$. Color white, yellowish green, pink; colorless in section. Found with tourmaline, apparently as an alteration product. Rare.

Pholidolite $\{K_2O \cdot 12(Mg,Fe)O \cdot Al_2O_3 \cdot 13SiO_2 \cdot 5H_2O?\}$ is monoclininc in pseudohexagonal flakes with perfect 001 cleavage. H. = 4. G. = 2.41. The axis X is sensibly normal to 001. $(-)\ 2V$ = 0° to 20°, $N_g = N_m = 1.545$, $N_p = 1.503$, $N_g - N_p = 0.042$. Color green; nearly colorless in section. Found in contact zones in Sweden. Rare.

GLAUCONITE[45] MONOCLINIC $KMg(Fe,Al)_3Si_6O_{18} \cdot 3H_2O$

PHYS. CHAR.—Usually in granules, rarely as large as 0.1 mm., long supposed to be amorphous, but actually composed of fine laminæ with distinct 001 and 101(?) cleavages. H. = 2. G. = 2.2–2.8. F. = easy.

OPT. PROP.—The acute bisectrix X is nearly normal to the 001 cleavage. $(-)\ 2V$ = 0° to 20° ±, N_g = 1.623 to 1.645, N_m nearly = N_g, N_p = 1.603 to 1.615, $N_g - N_p$ = 0.02 to 0.03 (Schneider); $(-)\ 2V$ = 16° to 40°, N_g = 1.610 to 1.644, N_m = 1.609 to 1.643, N_p = 1.590 to 1.612, $N_g - N_p$ = 0.018 to 0.032 (Ross[46]).

Color olive green, blackish green; by alteration, yellow to brownish. In section green with X = straw yellow to pale yellowish green, Y and Z = clear green to yellowish green, and $X < Y$ and Z.

OCCUR.—Only in marine sedimentary rocks, always associated with detrital minerals such as feldspar, quartz, etc. It is now being formed on ocean bottoms at depths of 600 to 5000 feet. It is usually closely associated with animal remains.

DIAG.—The microcrystalline texture of the grains and the color are rather characteristic.

Celadonite is chemically similar to glauconite; it is lamellar or fibrous with perfect 001 cleavage. H. = 1. G. = 2.7 ±. F. = 3. Soluble in HCl. The elongation is positive. $(-)\ 2V$ = small, $N_g = 1.638$, $N_m = 1.63$, $N_p = 1.625$, $N_g - N_p = 0.013$. Color olive to apple green with X = light yellow-green, Y and Z = dark green. An alteration product in igneous and metamorphic rocks.

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[42] A. F. Hallimond: *Mineral Mag.*, XX, 1924, p. 193.

[43] F. F. Grout and G. A. Thiel: *Am. Mineral.*, IX, 1924, p. 228.

[44] K. K. Landes: *Am. Mineral.*, X, 1925, p. 355.

[45] H. Schneider: *Jour. Geol.*, XXXV, 1927. See also A. F. Hallimond: *Mineral. Mag.*, XIX, 1922, p. 330, and C. S. Ross: *U. S. Nat. Mus. Proc.*, LXIX, 1926, No. 2.

[46] *Proc. U. S. Nat. Mus.*, LXIX, 1926, No. 2.

GANOPHYLLITE MONO. $a : b : c = 0.413 : 1 : 1.831$ $7MnO \cdot Al_2O_3 \cdot 8SiO_2 \cdot 6H_2O$?
$\beta = 86° 39'$

PHYS. CHAR.—Crystals short prismatic, acicular or bladed with perfect 001 cleavage;[47] also 010 cleavage.[48] Percussion figure as in mica.[47] Twinning on 001. H. = 4. G. = 2.84. F. = 3. Gelatinizes with HCl.

OPT. PROP.—Optic plane normal to 010 [47]; $X \wedge c$ = small; 2° (Larsen [48]), $\rho < v$ distinct. The following data suggest *two* minerals:

	Franklin [48]	Paisberg [48]	Paisberg [47]	San Jose [49]
(−) 2V =	very small	26°	24°	
N_g =	1.593	1.604	1.730	
N_m =	1.593	1.603 (1.608)	1.729	1.723
N_p =	1.563	1.573	1.705	
$N_g - N_p$ =	0.030	0.031	0.025	

Color brown with X = yellowish brown, Y and Z = colorless. May be colorless in section.

OCCUR.—In manganese (and zinc) deposits in Sweden and New Jersey. Very rare.

CHLORITE GROUP

The chlorite group includes certain hydrous silicates of aluminum (or Fe''' or Cr) and magnesium or ferrous iron; it has been shown [50] that some minerals, commonly assigned to the "serpentine group," are end members of this group, which is a unit, since the variations in composition are not discontinuous. These "serpentine" minerals contain no trivalent element, but being merely limiting cases of continuous variations, they are included in this group.

PHYS. CHAR.—Monoclinic (?) with perfect basal cleavage; the cleavage flakes are flexible but not elastic; twinning common as in the micas. H. = 2–3. G. = 2.6–3.0. Easily attacked by acids.

OPT. PROP.—The optic plane is parallel to 010 and the acute bisectrix X is (nearly) normal to 001. The birefringence varies from imperceptible to strong, but is weak in the common types. Dispersion is strong in some cases, producing abnormal interference colors.

The chlorites are nearly always green (whence the name), but may be white, pink, brown, blue or black.

OCCUR.—Chlorites are widely distributed in nature, being found in nearly all kinds of rocks; in some rocks they are abundant. They are the only essential constituent of chlorite schists. In igneous rocks they are always secondary, but more frequently due to hydrothermal than to weathering conditions. They are formed at the expense of micas, pyroxenes, amphiboles, garnets and olivines. They are also formed by " reaction " between minerals, and in propylite they may replace feldspar and other minerals.

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[47] A. Hamberg: *Geol. För. Förh.*, XII, 1890, p. 586.

[48] E. S. Larsen and E. V. Shannon: *Am. Mineral.*, VII, 152, and IX, 1924, p. 238.

[49] A. F. Rogers: *Am. Jour. Sci.*, CXCVIII, 1919, p. 443.

[50] A. N. Winchell: *Am. Jour. Sci.*, CCXI, 1926, p. 283.

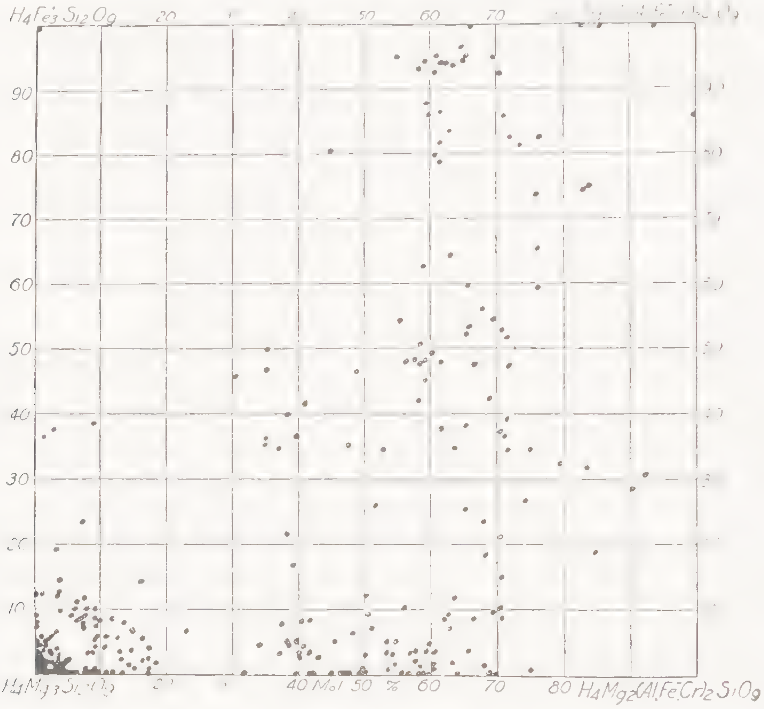

FIG. 303.—Variation in composition in the chlorite system.

DIAG.—Characterized by (usual) pale green color with distinct, though weak, pleochroism, low relief, weak birefringence and strong dispersion; also by flexible inelastic cleavage flakes and lack of alkalies.

CLASS.—The chief end members of the chlorite system include:

Nepouite	$H_4Ni_3Si_2O_9$	(Abbreviated Nep)
Antigorite	$H_4Mg_3Si_2O_9$	(Ant)
Ferroantigorite (or bowlingite?)	$H_4Fe_3Si_2O_9$	(FeAnt)
Amesite	$H_4Mg_2Al_2SiO_9$	(At)
Daphnite	$H_4Fe_2Al_2SiO_9$	(Dn)
Cronstedtite	$H_4Fe_2Fe_2SiO_9$	(Cr)
Magnesiocronstedtite	$H_4Mg_2Fe_2SiO_9$	(MgCr)
Kaemmererite	$H_4Mg_2Cr_2SiO_9$	(Kr)

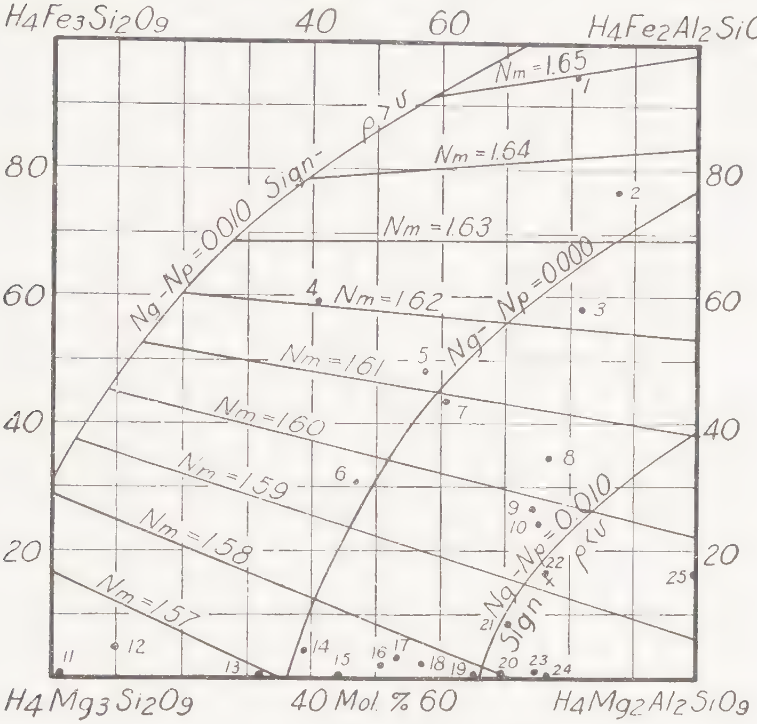

FIG. 304.—Relations of optic properties to composition in the chlorite system.

Excluding Ni, Fe''' and Cr as relatively rare, the chief subdivisions of the system may be defined as follows, on a chemical basis:

Name	%(At + Dn)	%(Ant + FeAnt)	(FeAnt + Dn)	%(Ant + At)
Antigorite	0–20	100–80	0–20	100–80
Jenkinsite	0–20	100–80	20–40	80–60
Penninite	20–40	80–60	0–20	100–80
Delessite	20–40	80–60	20–40	80–60
Clinochlorite	40–60	60–40	0–20	100–80
Diabantite	40–60	60–40	40–60	60–40
Corundophilite	60–80	40–20	0–20	100–80
Prochlorite	60–80	40–20	20–40	80–60
Ripidolite	60–80	40–20	40–60	60–40
Aphrosiderite	60–80	40–20	60–80	40–20
Thuringite	60–80	40–20	80–100	20–0
Amesite	80–100	20–0	0–20	100–80
Daphnite	80–100	20–0	80–100	20–0

For convenience in petrographic work a classification based on optic properties may be useful, as follows:

Name	Sign	N_m	$N_g - N_p$
Antigorite	−	1.56–1.58	0.004–0.010
Delessite	−	1.58–1.60	0.000–0.004
Jenkinsite	−	1.58–1.60	0.004–0.010
Diabantite	−	1.60–1.62	0.000–0.004
Aphrosiderite	−	1.62–1.64	0.000–0.004
Daphnite	−	1.64–1.66	0.000–0.004
Thuringite	−	1.64–1.66	0.004–0.010
Penninite	−	1.56–1.58	0.000–0.004
Penninite	+	1.57–1.60	0.000–0.004
Ripidolite	+	1.60–1.62	0.000–0.004
Clinochlorite	+	1.57–1.59	0.004–0.010
Prochlorite	+	1.59–1.61	0.004–0.010
Amesite	+	1.58–1.60	0.010–0.015±

These two classifications of chlorites are only roughly equivalent; the relations between them may be seen in Fig. 305.

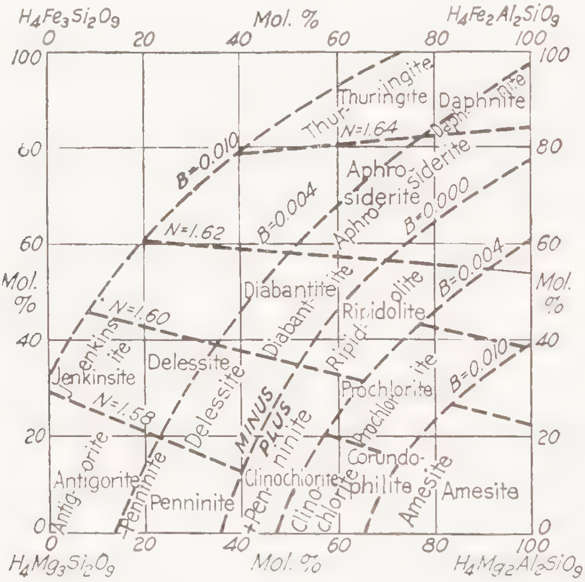

FIG. 305.—Chemical and optical classifications of the chlorite system.

NEPOUITE [51] MONOCLINIC (PSEUDOHEXAGONAL) $H_4Ni_3Si_2O_9$

COMP.—Usually contains Mg, thus grading toward antigorite.

PHYS. CHAR.—Basal plates with perfect 001 and good 010 cleavages. H. = 2–2.5. G. = 2.97–3.24, decreasing with increase of Mg, which may replace Ni in part. Slowly soluble in HCl.

OPT. PROP.—The optic plane is 010 and the acute bisectrix X is sensibly normal to

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[51] E. Glasser: *Comp. Rend.*, CXLIII, 1906, p. 1173; A. Lacroix: *Minéral. France*, IV, 1910, p. 741.

001. Optic angle small to sensibly zero. With Ni : Mg = 90 : 10, (−) 2V = very small, $N_g = N_m = 1.62–1.63$, $N_p = 1.59 \pm$, $N_g - N_p = 0.037$. With Ni : Mg = 30 : 70, (−) 2V = very small, $N_g = N_m = 1.56$, $N_p = 1.53$, $N_g - N_p = 0.03$.

Color greenish with X = green, Y = Z = greenish yellow.

Occur.—As a fine powder in a vein in serpentine, and as vermicular masses with nouméite in New Caledonia.

Diag.—Differs from nouméite in texture and optic properties; like antigorite except in birefringence.

Connarite is a closely related hydrous nickel silicate with perfect basal cleavage. H. = 2.6–3. G. = 2.5. It is apparently uniaxial with $N_o = 1.59 \pm$, $N_e = 1.56 \pm$, $N_o - N_e = 0.03 \pm$. Color yellowish green; faintly pleochroic. Found with siderite, quartz and phosphates in Germany. Very rare.

ANTIGORITE Monoclinic? (Pseudocubic) $H_4Mg_3Si_2O_9$

Comp.—Antigorite is here limited to types containing $(At + Dn)_{0-20}$, $(FeAnt + Dn)_{0-20}$ and $(Ant + FeAnT)_{100-80}$, $(Ant + At)_{100-80}$.

Phys. Char.—Nearly always pseudomorphous; also pseudocubic with perfect 001, good 010, and occasional 100 cleavages. H. = 3–4. G. = 2.55–2.58. F. = diff. Decomposed by HCl.

Opt. Prop.—The optic plane is 010; the negative acute bisectrix is normal to 001; elongation of lamellæ is therefore positive. Optic angle moderate. (−) 2E = 110° ±, $\rho > v$ weak, $N_g = 1.571$, $N_m = 1.570$, $N_p = 1.560$, $N_g - N_p = 0.011$ or less. Larsen reports [52] much lower indices, as follows: $N_g = 1.511$, $N_m = 1.502 \pm$, $N_p = 1.490$, $N_g - N_p = 0.021$. These need confirmation and explanation.

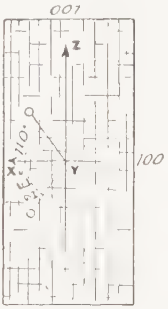

Fig. 306.—Optic orientation of antigorite.

Color green of various shades, grayish, yellowish, rarely white. In thin section (rarely colorless or) pale greenish with X = Y = pale greenish yellow, Z = pale green.

Inver.—Antigorite and chrysotilite seem to be dimorphous forms of the same compound; the mutual stability relationships are entirely unknown.

Occur.—Common in peridotites and abundant in serpentine resulting from their alteration; found also in other igneous and metamorphic rocks as an alteration product of olivine, pyroxene, amphibole, etc.

Diag.—Differs from chrysotilite in lamellar rather than fibrous habit, and in optic sign, weaker birefringence and larger optic angle.

Bastite is a coarse variety of antigorite; it is always pseudomorphous after pyroxene, usually enstenite, sometimes diopside It forms by regular gradual development so that one crystal of pyroxene is replaced by one crystal of bastite, in which the perfect 001 cleavage of the latter is parallel with the 010 parting of the former.

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[52] *U. S. Geol. Surv. Bull.* 679, 1921, p. 244.

Jenkinsite is a ferriferous antigorite with Mg : Fe = 80 : 20 to 60 : 40; lamellar; acute bisectrix X normal to 001 cleavage. (−) 2V = not large, $N_m = 1.59 \pm$, $N_g - N_p = 0.01 \pm$. Color olive green. Found on magnetite in New York. Rare.

Ekmannite [53] $\{H_4(Mn,Fe)_3Si_2O_9?\}$ seems to be a manganese-antigorite, although the name is applied also to types with much Fe_2O_3 and even Al_2O_3. Perfect 001 cleavage. G. = 2.79. X = *c*. (−) 2V = 0° or very small, $N_g = N_m = 1.670$, $N_p = 1.582$, $N_g - N_p = 0.088$. Color gray with X = colorless, Y = Z = pale green. Found in ore deposits. Very rare. A darker colored type with 7.07 Fe_2O_3 and 1.65 Al_2O_3 has (−) 2V = 0°, $N_g = N_m = 1.637$, $N_p = 1.581$, $N_g - N_p = 0.056$. Color black with X = nearly colorless, Y = Z = dark (greenish) brown. Rare.

PENNINITE MONOCLINIC (PSEUDOHEXAGONAL) $\left\{\begin{array}{l}(At + Dn)_{20-40}(FeAnt + Dn)_{0-20}\\(Ant + FeAnt)_{80-60}(Ant + At)_{100-80}\end{array}\right.$

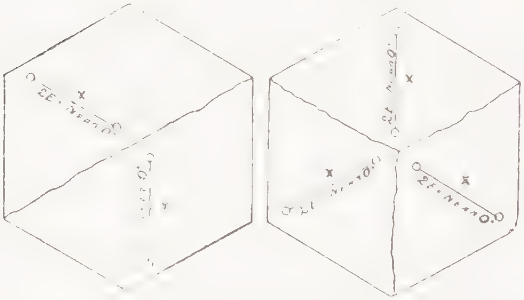
$a : b : c = 0.577 : 1 : 2.277 \quad \beta = 89° 40'$

PHYS. CHAR.—Lamellar with perfect 001 cleavage producing thin flexible inelastic lamellæ. Percussion and pressure figures like those of mica. Twinning on 001 with 001 as composition face (penninite law), also on 110 with 001 as composition face (mica law). H. = 2–2.5. G. = 2.6–2.84. F. = 5–6 with exfoliation. Decomposed by H_2SO_4.

OPT. PROP.—The optic plane is 010, and the acute bisectrix is sensibly normal to 001. Often sensibly uniaxial. Strong dispersion. Very weak birefringence. Sign variable even in a single thin section.

(+) 2E = 0° to small, $\rho < v$ strong.

$N_m = 1.565 - 1.58$, $N_g - N_p = 0.000$ to 0.004.



FIGS. 307, 308.—Optic orientation in penninite twins.

(−) 2E = 0° to small, $\rho > v$ strong.

$N_m = 1.57–1.60$, $N_g - N_p = 0.000$ to 0.003.

The "ultra blue" abnormal interference colors are quite characteristic, being found in only one other common mineral (clinozoisite) which has much higher relief. The colors are probably due to an isotropic condition for red light, while the crystal is anisotropic for blue light.

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[53] J. Jakob: *Schweiz. Min. Pet. Mit.*, III, p. 327, and IV, 1924, p. 51.

Color green of various shades; rarely red, pink, violet, yellow, white. Distinctly pleochroic with minimum absorption normal to 001:

Positive penninite	Negative penninite (or delessite)
X = green	very pale yellowish green to colorless
Y = green	green
Z = very pale yellowish green to colorless	green
Absorption $X = Y > Z$	$X < Y = Z$
Elongation −	+

Occur.—A very common alteration product, usually formed under hydrothermal conditions, from biotite, amphibole, pyroxene, garnet. In propylite it may replace feldspar. It is found in veins, in rock cavities and in all kinds of rocks.

Diag.—Characterized by pale-green color and weak pleochroism, very small optic angle, low relief, very weak birefringence and strong dispersion producing " ultra blue " interference colors.

Delessite is a ferriferous penninite with Mg : Fe = 80 : 20 to 60 : 40; it differs from penninite in being always negative with 2V = small, $N_m = 1.58$ to 1.60, $N_g - N_p$ = very weak to 0.004 ±. $X \wedge c = 0°$ to 7°. Color green or pink and pleochroic with X = pale green, pale yellow or colorless, Y = Z = green or pink. As the birefringence increases the abnormal interference colors become less distinct. Not rare. The name may be applied also to types described above as negative penninite.

CLINOCHLORITE (*Clinochlore*)

Monoclinic

$(At+Dn)_{40-60}(FeAnt+Dn)_{0-20}$
$(Ant+FeAnt)_{60-40}(Ant+At)_{100-80}$

$a : b : c = 0.577 : 1 : 2.277 \quad \beta = 89° 40'$

Phys. Char.—Similar to penninite; polysynthetic twinning common. H. = 2–2.5. G. = 2.65–2.78. F. = 6. Decomposed by H_2SO_4.

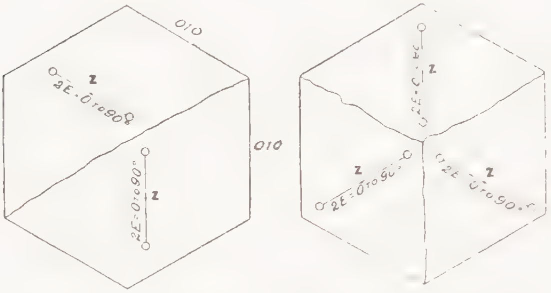
Opt. Prop.—The optic plane is 010 and the acute bisectrix Z is sensibly normal to 001. In rare cases it is reported that $Z \wedge \perp 001 = 2° 30'$. Optic angle variable even in a single lamella. Weak inclined dispersion with $\rho < v$. (+) $2E = 0°–70°$, $N_m = 1.57–1.59$, $N_g - N_p = 0.004–0.010$. Fine twinning bands common.

Color grass green to olive; rarely yellowish, pink, white. Pleochroic with X = Y = pale green, Z = pale yellowish green to colorless.

Occur.—Widely distributed, but not as abundant as penninite.

Diag.—Characterized by pale-green color and pleochroism, positive sign, negative elongation, distinctly biaxial character, common twinning.

The name clinochlorite is often confined to chlorites with $N_g - N_p = 0.010 \pm$ and distinct biaxial character. A colorless variety[54] of clinochlorite has been called *sheridanite*. A sample from Chester Co., Pa., has: (+) $2E = 0°$, $N_g = 1.576$, $N_m = N_p = 1.562$, $N_g - N_p = 0.014$. Rare.



FIGS. 309, 310.—Optic orientation in clinochlorite twins.

Diabantite is a ferriferous clinochlorite with Mg : Fe = 60 : 40 to 40 : 60; it is negative with $2V$ = small, $N_m = 1.60$-1.62, $N_g - N_p = 0.000$-$0.004 \pm$. Color and pleochroism usually stronger than in clinochlorite. Uncommon.

CORUNDOPHILITE MONOCLINIC $\left\{ \begin{array}{l} (At + Dn)_{60-80}(FeAnt + Dn)_{0-20} \\ (Ant + FeAnt)_{[illegible]}(Ant + At)_{[illegible]} \end{array} \right.$

$a : b : c = 0.577 : 1 : 2.277 \quad \beta = 89° 40'$

PHYS. CHAR.—Similar to penninite with laminæ somewhat more brittle. H. = 2.5. G. = 2.9.

OPT. PROP.—The optic plane is 010, and the acute bisectrix Z makes an angle of 8°–10° with a normal to 001. (+) $2E = 50° \pm$, $2V = 31°$, $\rho < v$ distinct. $N_m = 1.58$–$1.59 \pm$, $N_g - N_p = 0.010 \pm$. Color green; pleochroic with X = Y = deep blue green, Z = pale brownish green, nearly colorless.

OCCUR.—Intimately associated with corundum and diasporite. Rare.

DIAG.—Characterized by larger optic angle than common in the chlorite group; also by association with corundum.

Rumpfite is a name applied to chlorites of positive sign and with N_m less than 1.585 and $N_g - N_p$ about 0.010. The mineral is closely related to corundophilite. Rare.

Prochlorite is a name which is variously defined; it is here applied to ferriferous corundophilite with Mg : Fe = 80 : 20 to 60 : 40. It forms interlaced lamellæ or vermicular prisms or rosettes. H. = 2. G. = 2.8-2.9. The optic plane is 010 and the acute bisectrix Z is inclined about 2° to a normal to 001. (+) $2V = 0°$ to small, $\rho <$ strong. $N_m = 1.59$–1.61, $N_g - N_p = 0.004$–0.010. Color green; rarely bronze brown or greenish gray. Pleochroic with X = Y = green or yellowish green, Z = colorless or greenish yellow or brownish. Found as an alteration product in igneous and other rocks and as an essential constituent of some schists; also in large masses in some veins; in poikilitic growths in orthoclase, albite, quartz, calcite, axinite, prehnite, etc.

Ripidolite is sometimes used as a synonym of prochlorite, but is here applied to ferriferous corundophilite with Mg : Fe = 60 : 40 to 40 : 60. It is positive or negative in optic sign with a small optic angle. $N_m = 1.60$–1.62, $N_g - N_p = 0.000$ to 0.004. Color and pleochroism as in prochlorite, except that negative types have X = colorless or pale, Y = Z = greenish. Not rare.

Aphrosiderite has been regarded as a "leptochlorite," but is here applied to ferriferous corundophilite with Mg : Fe = 40 : 60 to 20 : 80. It is negative with $2V$ = small,

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[54] E. V. Shannon and E. T. Wherry: *Jour. Wash. Acad. Sci.*, XII, 1922, p. 239.

N_m = 1.62–1.64, $N_g - N_p$ = very weak. The optic plane is 010 and X is normal to 001. Color green with X = colorless or pale, Y = Z = green. Uncommon.

Thuringite has been regarded as a "leptochlorite," but is here applied to ferriferous corundophilite with Mg : Fe = 20 : 80 to 0 : 100, with changes in the state of oxidation of the iron in some cases. It is negative with 2V = small to moderate, N_m = 1.64–1.66, $N_g - N_p$ = 0.01 ±. Color olive to dark green with X = nearly colorless, Y = Z = dark green. Found in iron ores with garnet, etc. Uncommon.

Aerinite is a ferriferous chlorite of unknown composition characterized by blue color. It gives off water and turns to a wood brown color in the closed tube. Easily fusible. Soluble even in cold acid. Acute bisectrix X is nearly normal to the perfect 001 cleavage. (−) 2V = small, $\rho > v$ strong. Color deep blue with X = yellowish or colorless, Y = Z = dark cobalt blue. Rare.

AMESITE MONOCLINIC (PSEUDOHEXAGONAL) $H_4Mg_2Al_2SiO_9$

COMP.—The name is here applied to chlorites with $(At + Dn)_{80-100}(FeAnt + Dn)_{0-20}$ and $(Ant + FeAnt)_{20-0}(Ant + At)_{100-80}$.

PHYS. CHAR.—Crystals apparently hexagonal tablets with perfect 001 cleavage; laminæ somewhat brittle. H. = 2.5. G. = 2.8. F. = 7, but exfoliates slightly. Partly decomposed by acid.

OPT. PROP.—The optic plane is 010, and the acute bisectrix Z is nearly normal to the 001 cleavage. (+) 2V = small, N_m = 1.58–1.60, $N_g - N_p$ = 0.015 ±. For example:[55] N_g = 1.612, $N_m = N_p$ = 1.597, $N_g - N_p$ = 0.015. Color pale bluish green; colorless in thin section.

OCCUR. Known only at Chester, Mass., with corundum and diasporite.

DIAG.—Characterized by maximum birefringence for a chlorite which is colorless in section.

DAPHNITE MONOCLINIC (PSEUDOHEXAGONAL) $H_4Fe_2Al_2SiO_9$

COMP. The name is here applied to chlorites with $(At + Dn)_{80-100}(FeAnt + Dn)_{80-100}$ and $(Ant + FeAnt)_{20-0}(Ant + At)_{20-0}$.

PHYS. CHAR. In small concentric and radiated aggregates with perfect 001 cleavage; laminæ somewhat flexible. H. = 2. G. = 3.0. F. = easy. Easily decomposed by HCl.

OPT. PROP.—The optic plane is 010 and the acute bisectrix X is sensibly normal to the 001 cleavage. (−) 2V = 0° ±, N_m = 1.64–1.66, $N_g - N_p$ = 0.000–0.004. Color dark green with X = pale yellowish, Y = green, Z = olive green.

OCCUR.—With quartz and arsenopyrite. Rare.

DIAG.—Characterized by high refringence for a chlorite.

CRONSTEDTITE MONOCLINIC (PSEUDOHEXAGONAL) $H_4Fe''_2Fe'''_2SiO_9$

$a : b : c = ? : 1 : 2.17 \quad \beta = 90° \pm$

PHYS. CHAR.—Crystals 3- or 6-sided pyramids; also fibrous divergent; perfect 001 cleavage, somewhat elastic. H. = 3.5. G. = 3.45. F. = 5 with frothing. Gelatinizes with HCl.

OPT. PROP.—The optic plane is probably 010 and the acute bisectrix X is sensibly normal to the 001 cleavage. (−) 2E = 0° ±, N_m = 1.80 ±, $N_g - N_p$ = strong. Color coal to brownish or greenish black with dark olive green streak and X = dark reddish brown or emerald green, Y = Z = olive green to nearly opaque.

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[55] E. V. Shannon: *Am. Jour. Sci.*, CXCIX, 1920, p. 96.

Occur.—With limonite, quartz, etc., in ore deposits. Rare.

Chamosite is a chloritic mineral rich in iron of uncertain formula. It has 2E = very small about X, N = 1.64, $N_g - N_p = 0.010$ to 0.012 (Slavik [56]). Weakly pleochroic with X = yellowish or colorless, Y = Z = pale green. Found in sediments, in some cases pure enough to form an iron ore.

Magnesiocronstedtite ($H_4Mg_2Fe'''_2SiO_9$) is unknown even approximately pure, but seems to enter some chlorites in notable amounts.[57] The optic properties are unknown, but the refringence and birefringence should be increased as compared with amesite.

Kaemmererite ($H_4Mg_2Cr_2SiO_9$) is also unknown in the pure state, but enters chlorites to at least about 35 per cent. With about 15 mol. per cent of kaemmererite (and 25 amesite and 60 antigorite) the chlorite [58] is negative with 2E = very small, X normal to 001, $N_g = N_m = 1.590$, $N_p = 1.587$, $N_g - N_p = 0.003$. Color purple with X = pale red purple, Y = Z = red purple. As compared with Al, Cr tends to change the sign, but has little effect on N_m; it also changes the color to lavender or purple. Such chlorites are rare.

STRIGOVITE MONOCLINIC? (PSEUDOHEXAGONAL) $H_4Fe_2(Al,Fe)_2Si_2O_{11}$

Comp.—Perhaps a chlorite with interatomic silica.

Phys. Char.—Crystals minute 6-sided prisms, also in plates and fibers. H. = 1. G. = 3.14. F. = 6. Easily decomposed by acid.

Opt. Prop.—The acute bisectrix X is nearly or quite normal to the plates and (−) 2V = 0° ±, $N_g = N_m = 1.67$, $N_p = 1.65$, $N_g - N_p = 0.02$. Color dark green with X = pale greenish, Y = Z = nearly opaque.

Occur.—A coating in druses in granite. Very rare.

Saponite is a hydrous silicate of magnesium and aluminum of uncertain formula. Microcrystalline or apparently amorphous. Soft. G. = 2.26 ±. F. = 6. Attacked by H_2SO_4. Minute scales are uniaxial negative with $N_o = 1.555$, $N_o - N_e = 0.01$ ±. Color white or grayish. Found in serpentine. Rare.

Bowlingite [59] is very imperfectly known as to composition, but seems to be a hydrous ferromagnesian silicate. Part of the iron is oxidized to the ferric state in yellow and brown varieties. It is fibrous or lamellar with perfect 001 cleavage. H. = 2. Easily soluble in HCl. The optic plane is 010; the acute bisectrix X is sensibly normal to 001. (−) 2E = 0°–40°, $N_m = 1.6$ ±, $N_g - N_p = 0.025$ ±. Color green or yellow to reddish brown, apparently varying with state of oxidation of the iron. Pleochroic in section with:

X =	greenish yellow	pale yellow	reddish yellow
Y =	clear green	clear yellow	reddish yellow
Z =	green	golden yellow	dark reddish yellow

Bowlingite is an alteration product of ferriferous olivine in basic igneous rocks, notably in the Lake Superior region. The bowlingite often orients itself upon the olivine, a single crystal of the latter changing to a single crystal of the former with 001 of bowlingite coinciding with 001 of olivine and the optic plane of bowlingite parallel to 010 of olivine. In other cases a crystal of olivine may change to a fibrolamellar mass of bowlingite. Secondary magnetite may be more or less enclosed in the bowlingite.

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[56] *Min. Abst.*, I, 1922, p. 264.

[57] Twenty-three per cent in Doelter's analysis 88 (*Hdb. Mineralch.*, II, 2, p. 647).

[58] E. V. Shannon: *Proc. U. S. Nat. Mus.*, LVIII, 1920, p. 378.

[59] The "viridite" of Kretschmer (*N. Jahrb. Min.*, 1918, p. 19) is described as $H_6Fe_4Si_2O_{11}$; it is perhaps an altered bowlingite. It has G. = 2.89, $Z \wedge c = 0°–13°$, Y = *b*, N = 1.85, $N_g - N_p = 0.029$. Color green. Rare.

Bowlingite is distinguished from antigorite by color, pleochroism and much stronger birefringence. It differs from goethite, which is another common alteration product of olivine, by a refringence lower than that of olivine, while that of goethite is higher than that of olivine.

Iddingsite [60] ($H_8MgFe_2Si_3O_{14}$?) is orthorhombic and pseudomorphous after olivine. Lamellar with distinct 100, 001 and 010, and indistinct 101 cleavages. H. = 3. G. = 2.5 2.84. Attacked by HCl which abstracts the iron. Optic plane is 010; X = *a*. The mineral must vary decidedly in composition since the optic properties show wide variations, as illustrated below:

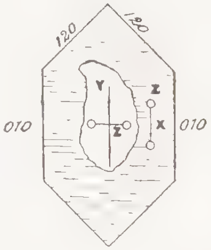

Fig. 311.—Relation of bowlingite to olivine.

Locality	N_g	N_m	N_p	N_g-N_p	2V	Disp.	Sign
Race Creek, Colo.	1.655	1.650	1.608	0.047	35°–42°	$\rho < v$	−
La Jara Creek, Colo.	1.718	1.715	1.674	0.044	25°–45°	$\rho < v$	−
Gato Creek, Colo.	1.74	1.73	1.70	0.040	20°–25°	.....	−
Uncomp. Quad., Colo.	1.74	1.72	1.70	0.040	Large	$\rho > v$	+
So. Elk Creek, Colo.	1.745	1.735	1.710	0.035	60° ±	.....	+
Bernards Ferry, Ida.	1.754	1.746	1.710	0.044	50°	.....	−
Wicher Mt., Colo.	1.76	1.74	1.71	0.050	Large	$\rho < v$	−
Daton Peak, Colo.[61]	1.760	1.725	1.720	0.040	35° 42°	.....	−
Carmelo Bay, Calif.	1.765	1.745	1.723	0.042	Large	$\rho < v$	−
Death Valley, Calif.	1.765	?	1.730	0.035	42°	.....	−
Mill Gulch, Colo.	1.768	1.763	1.724	0.044	40°	$\rho < v$	−
Brazos R., N. Mex.	1.864	1.846	1.792	0.072	60°–90°	$\rho < v$	−
Brazos R., N. Mex.	1.864	1.827	1.792	0.072	80° ±	$\rho > v$	+

The dispersion is strong with $\rho < v$ over X in all cases. Color deep reddish brown to ruby red with more or less pleochroism except in basal sections and X < Y < Z. It is an alteration product of olivine, apparently the same as bowlingite. Not very rare.

CLINTONITE GROUP

In a broad sense the clintonite group includes margarite, seybertite, chloritoid, etc., which are characterized physically as the *brittle* micas, as compared with the *elastic* or true micas and the *flexible* micas or chlorites. The name is here applied only to the seybertite series. Chemically the clintonites differ from the micas and the chlorites in containing calcium as an essential constituent. The end member molecules are still in doubt, and therefore the relations between composition and optic properties are unknown. Tschermak suggested the molecules given below, which are not satisfactory for recent analyses.

CLINTONITE Monoclinic (Pseudohexagonal)

$a : b : c = 0.577 : 1 : 3.244 \quad \beta = 90° \pm$

$$\begin{cases} mH_2CaMg_4Si_3O_{12} + \\ nH_2CaMgAl_6O_{12}(?) \end{cases}$$

Phys. Char.—Crystals very similar to those of biotite; common multiple twinning on the mica law. Percussion and pressure figures interchanged in position as compared with the micas. Perfect 001 cleavage. H. = 4.5–5 on 001, 5.5–6 on other faces. G. = 3.0 3.15. F. = 7. Insoluble.

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[60] C. S. Ross and E. V. Shannon: *Proc. U. S. Nat. Mus.*, LXVII, 1925, Art. 7

[61] According to the indices the sign must be positive.

Opt. Prop.—The optic plane is 010 in *xanthophyllite* and *brandisite*; it is normal to 010 in *seybertite*; in all three the acute bisectrix X is nearly normal to 001 (89.5° in xanthophyllite). Optic angle small; relief moderate.

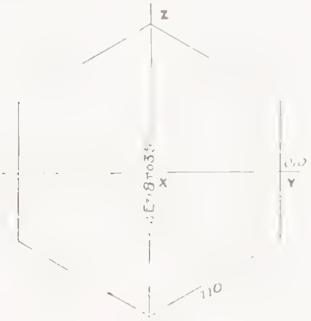

Fig. 312.—Optic orientation of brandisite.

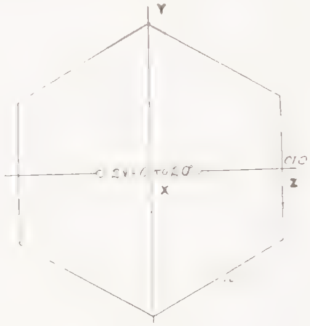

Fig. 313.—Optic orientation of seybertite.

	Xanthophyllite	Brandisite	Seybertite
Mol. % $H_2CaMgAl_6O_{12}$ =	55	57	61
(−) 2V =	2°–40°, $\rho < v$ weak	18°–35°	5°, $\rho < v$ weak
N_g =	1.661	1.660	1.658
N_m =	1.660	1.660	1.657
N_p =	1.649	1.648	1.646
$N_g - N_p$ =	0.012	0.012	0.012

Color of xanthophyllite leek to bottle green, of brandisite yellowish to dark green, rarely reddish gray, and of seybertite reddish brown, yellowish or copper red with pearly submetallic lister. Pleochroic in thin section, as follows:

	Xanthophyllite	Brandisite	Seybertite
X =	reddish brown	pale orange yellow	colorless
Y = Z =	green	pale green	pale brownish yellow

All the preceding types contain about 3 per cent of iron oxide; a colorless clintonite from Pargas, Finland,[62] with only traces of iron gave: optic plane parallel to 010, X nearly normal to 001, (−) 2V = 2°–6°, $N_g = 1.638$, $N_g - N_m = 0.0003$; dispersion not noticeable.

Occur.—Xanthophyllite is found in chlorite schists in the Urals, brandisite in contact rocks in the Tyrol, and seybertite in limestone with serpentine. Rare.

Diag.—Differ from micas in the position of the percussion and pressure figures, the hardness, the brittleness, and the weaker birefringence; differ from chlorite in stronger birefringence, greater hardness, brittleness and weak dispersion. Differ from chloritoid in negative sign, small optic angle and pleochroism.

Kossmatite [63] ($H_{18}Ca_7Mg_3Al_6FSi_7O_{42}$?) is closely related to clintonite; perfect basal cleavage, yielding brittle laminæ. H. = 2.5. F. = difficult. Optically nearly uniaxial and *positive* with (+) 2E = 14° 15′, N_g = ?, $N_m = 1.564$, $N_p = 1.560$ (for 529 $\mu\mu$). Colorless. Found in dolomite with corundum at a contact. Rare.

[62] A. Laitakari: *Bull. Com. Géol. Finlande*, No. 54, 1920, p. 87.

[63] O. H. Erdmannsdörffer: *Cent. Min.*, 1925, A, p. 69.

MARGARITE MONOCLINIC (PSEUDOHEXAGONAL) $H_2CaAl_4Si_2O_{12}$

PHYS. CHAR.—Crystals rare; thin tabular to lamellar with perfect 001 cleavage. Common twinning on the mica law. Cleavage laminæ brittle. Percussion figure as in mica. H. = 3.5–4.5. G. = 3.0–3.1. F. = 6. Attacked by H_2SO_4.

OPT. PROP.—The optic plane is normal to 010; the acute bisectrix X makes an angle of about 6° with a normal to 001. Optic angle variable. $(-)\ 2V =$ small to 67°, $\rho < v$, $N_g = 1.645$, $N_m = 1.643$, $N_p = 1.632$, $N_g - N_p = 0.013 \pm$ (Larsen); $N_g = 1.630$, $N_m = 1.629$, $N_p = 1.620$, $N_g - N_p = 0.010$ (Shannon [64]). Color grayish, reddish, white, pink, yellowish; colorless in section.

ALTER.—Changes to a brownish yellow hydrous micaceous mineral, known as *dudleyite*.

OCCUR.—In metamorphosed rocks with corundum from which it may be derived; also in mica schist with tourmaline and staurolite.

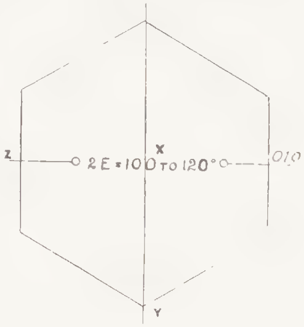

FIG. 314.—Optic orientation of margarite.

DIAG.—Differs from micas in weaker birefringence and from chlorite and chloritoid in the absence of color in thin section.

CHLORITOID TRICLINIC OR MONOCLINIC (PSEUDOHEXAGONAL) $H_2FeAl_2SiO_7$

COMP.—According to Simpson [52] *chloritoid* is $H_2FeAl_2SiO_7$, *sismondite* is $H_2(Fe,Mg)Al_2SiO_7$ and *ottrelite* is $H_2(Fe,Mn)Al_2SiO_7$; analyses showing more SiO_2, supposed to distinguish *venasquite*, are due to quartz inclusions.

PHYS. CHAR.—Similar to micas in form and twinning. Basal cleavage not as perfect as in micas although accentuated by twinning. Imperfect prismatic (110) cleavages and 010 parting. Cleavage laminæ not flexible. H. = 6.5. G. = 3.26–3.57. F. = 6, but becomes magnetic. Decomposed by H_2SO_4.

OPT. PROP.—The optic plane is parallel or nearly parallel with 010; the acute bisectrix Z makes an angle of 3° to 30° with a normal to 001; the optic angle is equally variable. Horizontal dispersion distinct with $\rho > v$, strong. Idaho chloritoid has strong crossed dispersion.[65]

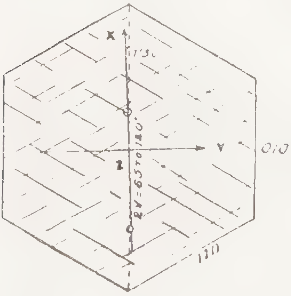

FIG. 315.—Optic orientation of chloritoid.

	Chloritoid		Ottrelite	Sismondite
$(+)\ 2V =$	36°–60°	Mod.	variable	45°–60°
$N_g =$	....	1.731		
$N_m =$	1.73 –1.77	1.722	1.73	1.74
$N_p =$	....	1.720		
$N_g - N_p =$	0.007–0.016	0.011	0.01	0.01
$Z \wedge c =$	3°–20° {17° (violet) 21° (red)}	18°–21°	25° ±	2° (violet) 4° (red)

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[64] *Proc. U. S. Nat. Mus.*, LVIII, 1920, p. 469.

[52] *Geol. Surv. W. Austral. Bull.* 64, 1915, p. 64.

[65] E. V. Shannon: *U. S. Nat. Mus. Bull.* 131, 1926, p. 377.

Color dark gray to greenish black with strong pleochroism, as follows:

X = olive green	colorless to pale brownish green	grass green	grass green	blue
Y = plum to indigo blue	indigo blue	slate blue	pale green	olive green
Z = yellow to colorless	pale greenish brown	yellow green	pale yellow	yellow green

INCL.—Usually rich in inclusions, especially of quartz, but also of magnetite, ilmenite, rutile, tourmaline; also, in some ottrelite, carbonaceous matter which may be regularly arranged.

ALTER.—Changes to muscovite and penninite.

OCCUR.—Only in crystalline schists where it may be abundant.

DIAG.—Color, pleochroism, high relief, weak birefringence, large optic angle (as compared with chlorite) and strong dispersion are quite characteristic. The cleavages are numerous, but not micaceous; the laminæ are not elastic nor flexible; the specific gravity is high.

USSINGITE[66] TRICLINIC (PSEUDOMONOCLINIC) $HNa_2AlSi_3O_9$

PHYS. CHAR.—Crystals unknown; perfect 001, imperfect 110 and $1\bar{1}0$ cleavages with $001 \wedge 110 = 70° 21'$, $001 \wedge 1\bar{1}0 = 71° 30'$, $110 \wedge 1\bar{1}0 = 90° 28'$. Twinning common on 010. H. = 6.5. G. = 2.5. F. = easy with swelling. Gelatinizes with HCl.

OPT. PROP.—The extinction in the zone normal to 010 attains a maximum of about 6°; the acute bisectrix Z makes an angle of about + 33° with a normal to 001 in sections parallel with 010; in sections normal to 001 and to 010 the extinction angle on 010 is about 4°. (+) $2V = 39°$, $(2E = 54°–63°)$, $N_g = 1.5454$, $N_m = 1.5082$, $N_p = 1.5037$, $N_g - N_p = 0.0417$. In 001 cleavage flakes the birefringence is 0.0164. Color pale to dark violet red without pleochroism.

OCCUR.—With sodalite and feldspar in pegmatite in Greenland. Very rare.

DIAG.—Negative relief, strong birefringence and color are distinctive.

12. HYDROUS SILICATES OF Al (Cr, Fe‴, Mn‴) AND ONE OR MORE OTHER BASES

THE ZEOLITES

The minerals of the zeolite group[1] are closely related in many characters, but they are quite diverse in crystal habit and symmetry. One of the group is isometric (faujasite), edingtonite, natrolite and gismondite are tetragonal in aspect (actually orthorhombic and monoclinic), chabazite and gmelinite, are rhombohedral or very nearly so, thomsonite, gonnardite, stellerite, epidesmine, echellite, erionite, and ferrierite are orthorhombic, mesolite and pseudomesolite are triclinic and the others are monoclinic.

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[66] O. B. Böggild: *Zeit. Kryst.*, LIV, 1915, p. 120. A. E. Fersman: *Am. Mineral.*, XI, 1926, p. 289.

[1] Apophyllite, gyrolite, etc., are not here included among the zeolites since they contain no aluminum; analcite is also excluded, since it does not intumesce on heating, contains very little water, and is formed under conditions unlike those which produce zeolites.

Comp.—The composition of many zeolites is expressed in Fig. 316 according to the theory of the writer.[2]

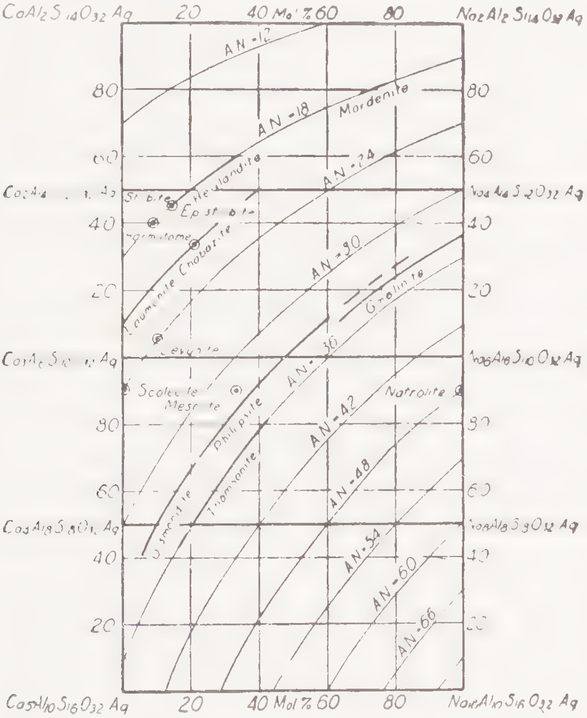

Fig. 316.—Variations in composition in the chief zeolites. A.N. = alkali number or number of Na + Ca atoms to 240 oxygen atoms.

Phys. Char. Many zeolites are fibrous to prismatic; a few are equant rhombohedral, pyramidal or octahedral. Hardness and specific gravity are distinctly less than those of corresponding anhydrous silicates; H. = 3.5–5.5; G. = 2–2.4 (rarely 2.7 ±). Decomposed by acid, usually with gelatinization. Readily fusible, in most cases with intumescence.

Opt. Prop.—The zeolites are characterized by low refringence and negative relief; with few exceptions (especially thomsonite) they have weak (to zero) birefringence; nearly all zeolites are decidedly fibrous in habit, the exceptions being the isometric faujasite, the pseudotetragonal edingtonite and gismondite, the rhombohedral chabazite and gmelinite, and the monoclinic heulandite and brewsterite which have perfect 010 cleavage. Zeolites are white or colorless except when stained by impurities; they are all colorless in thin section except for chlorastrolite and certain artificial zeolites.

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[2] *Am. Mineral.*, X, 1925, pp. 97, 112, 145 and 166.

ALTER. Being themselves alteration products, the zeolites do not easily change to other minerals, but in some cases they have been observed to alter to kaolinite, or to calcite, or to an isotropic substance. Under other conditions they may be transformed to albite, or prehnite. By artificial fusion and recrystallization some of them will yield anorthite or a calcium-albite.

OCCUR.—The zeolites are practically always secondary minerals formed by the hydration of aluminum silicates of calcium, sodium, etc. They are derived chiefly from feldspars, but also from nephelite, leucite, sodalite, etc. They are found especially in amygdaloidal cavities, fractures and other openings in rocks of many types, and they are notably abundant in igneous rocks of the gabbro and basalt groups. They are found also in some metalliferous veins, especially where the gangue is limestone, and in the deposits of hot springs, where they have in some cases been formed within historic time, and are still being formed. Finally, phillipsite is produced at great depths on the ocean bottom by the action of the salt water upon the basic volcanic dust beneath it. The zeolites are commonly associated with calcite, prehnite, pectolite, apophyllite, datolite.

DIAG.—As compared with other silicates zeolites are characterized by low refringence, weak birefringence, inferior hardness, low specific gravity, lack of color, abundant tenor of water, and occurrence as secondary products; most of them are fibrous.

Faujasite is easily distinguished from all other zeolites by its isotropic character; *chabazite* and *gmelinite* are similar in having very weak birefringence; they have a variable, but small, optic angle of either sign. *Gismondite* has a large optic angle of negative sign with $N_g - N_p = .008$; its exterior form is that of a tetragonal bipyramid produced by complex twinning of monoclinic units. *Heulandite* and *brewsterite* are usually flattened parallel to the perfect 010 cleavage with more or less vertical elongation. Both have the positive acute bisectrix normal to the cleavage whose direction is therefore negative. The optic angle is quite variable, but usually small, in heulandite; it is large in brewsterite. The maximum extinction angle in the vertical zone is very small in heulandite; it is about 22° in brewsterite.

Edingtonite has rather high indices of refraction and rather strong birefringence for a zeolite; the optic angle is large and of negative sign; crystals are minute and apparently tetragonal pyramids.

All the other zeolites are fibrous and may be divided into three classes according as the elongation is positive, ± or negative. Those with positive elongation have maximum extinction angles, as measured on that direction, as follows: natrolite 0°, epistilbite 9°, pseudomesolite, 20°, phillipsite 11°–30°, laumontite 25°–30°.

Those with ± elongation have maximum extinction angles, as measured on that direction, as follows: thomsonite 0°, mesolite 5°, mordenite 15°, chlorastrolite 20°, harmotome 28°.

Those with negative elongation have maximum extinction angles, as measured on that direction, as follows: wellsite 2°, bavenite 2°, stilbite 5°, scolecite 15°, lintonite 19°.

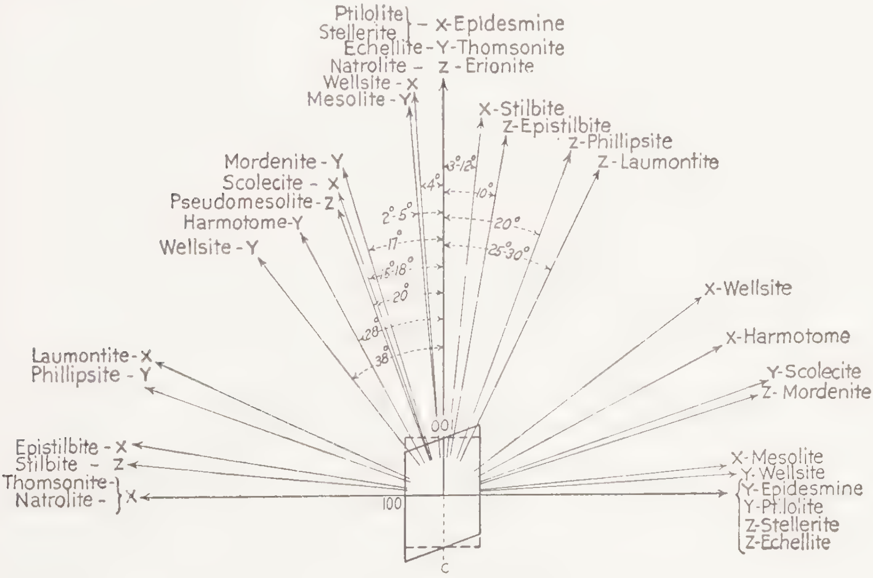

FIG. 317.—Optic orientation of the fibrous zeolites.

The optic orientation of fibrous zeolites as seen in section parallel with 010 is given in Fig. 317.

FAUJASITE ISOMETRIC $Na_2CaAl_4Si_{10}O_{28} \cdot 20H_2O$?

PHYS. CHAR.—Crystals octahedral; twinning on 111. Distinct 111 cleavage. H. = 5. G. = 1.92. F. = 3. Decomposed by acid.

OPT. PROP.—Normally isotropic with N = 1.48, but loss of a little water changes it to anisotropic, uniaxial, positive, with N = 1.48 ± and weak birefringence, the octahedron consisting of eight pyramidal segments each having an octahedral face for the base and an optic axis normal thereto. The birefringence decreases on warming (even in warm balsam) and at about 150° C. (having lost $12H_2O$) the mineral is again isotropic. Further heating changes it to uniaxial, negative. Upon cooling in damp air, the water is taken up again and the optic changes reversed.

Colorless, white or stained; colorless in section.

Occur.—With augite in limburgite in Baden, etc. Rare.

Diag.—Differs from other zeolites in its isotropic character.

CHABAZITE GROUP

The constituent molecules of the chabazite group are still under discussion, but it is clear that considerable variations exist in the Al : Si ratio as well as in the Na : Ca ratio. In his recent work Tschermak[3] recognizes four Ca molecules in the group, each containing $CaAl_2Si_2O_8 \cdot 4H_2O$, and respectively, $H_8Si_4O_{12}$, $H_4Si_2O_6$, H_4SiO_4 and $H_2Si_2O_3$.[4] Groth[5] prefers molecules based on the work of

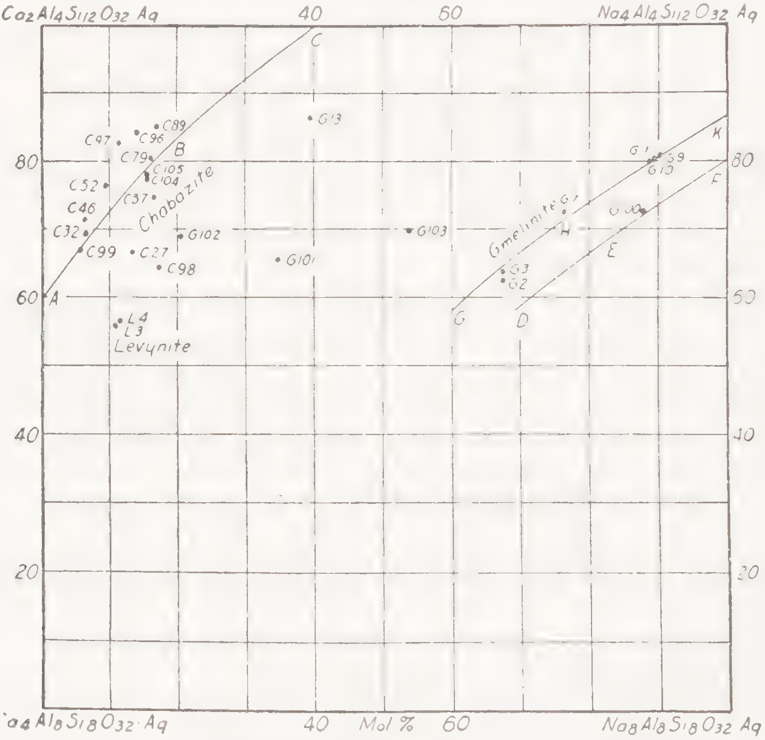

Fig. 318.—The composition of chabazite and related zeolites.

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[3] *Sitz. Akad. Wiss. Wien.*, CXXVI, 1917, p. 541, and CXXVII, 1918, p. 177.

[4] Si_2O_5 (= $H_2Si_2O_5$?).

[5] *Mineral. Tabellen*, 1921, p. 124.

Pirsson,[6] Lemberg[7] and Streng,[8] as follows: $(Ca,Na_2)Al_2Si_6O_{16} \cdot 8H_2O$ and $(Ca,Na_2)_2Al_4Si_4O_{16} \cdot 8H_2O$. The writer[9] has argued that chabazite and gmelinite are chemically as well as physically distinct; that crystals apparently showing a gradation between them have been modified in composition after formation by an exchange of bases under valence control; and that chabazite forms a series from $Ca_7Al_{14}Si_{26}O_{80} \cdot 40H_2O$ to $(Na,K)_4Ca_3Al_{10}Si_{30}O_{80} \cdot 40H_2O$ and gmelinite a series from $Na_5CaAl_7Si_{13}O_{40} \cdot 20H_2O$[9a] to $Na_6Al_6Si_{14}O_{40} \cdot 20H_2O$.

CHABAZITE SERIÈS

CHABAZITE Pseudohexagonal $mCa_7Al_{14}Si_{26}O_{80} \cdot 40H_2O +$
$c = 1.086$ | $n(Na,K)_4Ca_3Al_{10}Si_{30}O_{80} \cdot 40H_2O$
Mono. $a : b : c = 0.463 : 1 : 0.341$ $\beta = 83° 31'$

Phys. Char.—Crystals often simple rhombohedrons resembling a cube since the rhombohedral angle is 85° 14′; also more complex, or 0001 tablets. Penetration twins on 0001. Distinct rhombohedral cleavage. H. = 4–5. G. = 2.08–2.16. F. = 3 with intumescence. Decomposed by HCl.

Opt. Prop.—Chabazite crystals are usually biaxial, basal sections being divided into six sectors of varying extinction and having the optic planes in different positions. The units are probably triclinic (or monoclinic) and the rhombohedral external form is the result of twinning on 110 and $1\bar{1}0$; the pseudorhombohedral cleavage is considered to be actually cleavage parallel to 001, 100 and 010 of the triclinic unit. Some crystals are strictly uniaxial; others are uniaxial in some parts and biaxial in others. The optic angle is variable, but small. The sign is negative in some crystals and positive in others. These peculiarities have been explained in three different ways: 1, according to Brauns[10] the component molecules of chabazite are $CaAl_2Si_6O_{16} \cdot 8H_2O$ and $Ca_2Al_4Si_4O_{16} \cdot 8H_2O$ and the first is positive while the second is negative; 2, according to Pirsson[6] the

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[6] *Am. Jour. Sci.*, CXLII, 1891, p. 57.

[7] *Zeit. Deutsch. Geol. Ges.*, XXXIX, 1887, p. 582. Lemberg produced an artificial "basic chabazite" having the composition $Na_2Al_2Si_3O_{10} \cdot 6H_2O$.

[8] *Ber. Oberhess. Gesell. Natur.*, XVI, 1877, pp. 74–123. Doelter: *Hdb. Mineralch.*, II, 3, 1921, p. 85.

[9] *Am. Mineral.*, X, 1925, p. 145.

[9a] This formula is incorrectly given as $Na_4Ca_2Al_7Si_{13}O_{40} \cdot 20H_2O$ in *Am. Mineral.*, X, 1925, pp. 147 and 170.

[10] *Optische Anomalien*, Leipzig, 1891.

Ca-chabazites are positive and the Na-chabazites (gmelinites) are negative; 3, according to Rinne[11] fully hydrated chabazites are positive; slight heating changes them to negative, and further heating changes them back to the positive condition, but with *strong* birefringence; according to Grandjean[12] anhydrous gmelinite is uniaxial positive with $N_g - N_p = 0.027$.

(±) $2V = 0°–32°$, $N_g = 1.480–1.490$, $N_m = ?$, $N_p = 1.478–1.485$, $N_g - N_p = 0.002–0.010$, usually very weak.

Color white or pink. Colorless in section.

Chabazite is remarkable even among the zeolites for its ability to change its composition as to H_2O and as to Na or Ca, without destroying the crystal.

Occur.—In cavities in volcanic rocks often associated with phillipsite; in fractures in crystalline limestones and schists with stilbite, laumontite, etc.; abundant as a recent deposit of certain hot springs.

Diag.—Differs from gmelinite in composition and cleavage, and from other zeolites in external crystal form, very weak birefringence and small optic angle.

GMELINITE SERIES[13]

GMELINITE Pseudohexagonal $\left\{ \begin{array}{l} m\mathrm{Na_5CaAl_7Si_{13}O_{40} \cdot 20H_2O} \\ + n\mathrm{Na_6Al_6Si_{14}O_{40} \cdot 20H_2O} \end{array} \right.$

$c = 1.017$

Mono. $a : b : c = 0.457 : 1 : 0.339 \quad \beta = 82° \, 23'$

Phys. Char.—Crystals hexagonal or rhombohedral with vertical striations; penetration twins on 0001 or $10\bar{1}1$. Distinct prismatic cleavage and 0001 parting. H. = 4.5. G. = 2.04–2.17. F. = 3 with intumescence. Decomposed by HCl.

Opt. Prop.—Similar to chabazite in all respects. (±) 2V = small, $N_g = 1.465–1.480$, $N_m = ?$, $N_p = 1.464–1.479$, $N_g - N_p = 0.001–0.009$, usually very weak.

Colorless, white or tinted by impurities; colorless in section.

Occur.—In cavities in igneous and schistose rocks.

Diag.—Differs from chabazite in composition and cleavage and from other zeolites in external form, very weak birefringence and small optic angle.

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[11] *Sitz. Akad. Wiss. Berlin*, 1890, p. 1163.

[12] *Comp. Rend.*, CXLIX, 1909, p. 866; *Bull. Soc. Fr. Min.*, XXXIII, 1900, p. 5.

[13] Regarding constituent molecules and relationships see chabazite group, p. 390.

Levynite $\{NaCa_4Al_9Si_{16}O_{50} \cdot 25H_2O(?)\}$ is related in form to the chabazite group. It is (pseudo?) rhombohedral with $c = 1.114$. Penetration twins on 0001; indistinct rhombohedral cleavage. H. = 4–4.5. G. = 2.09–2.16. F. = 2.5 with intumescence. Gelatinizes with HCl. Uniaxial negative with $N_o = 1.496$, $N_e = 1.491$, $N_o - N_e = 0.005$. Color white or tinted by impurities. Found in cavities in basalt, etc.

THOMSONITE SERIES

The formula of thomsonite is still uncertain; Wherry[14] gives two formulas for two types, but there seems to be an isomorphous series (or system?) from the first molecule given below nearly to a 1 : 1 ratio with the second molecule. Thomsonite differs from plagioclase not only in its water, but also in containing more (Ca + Na) atoms per 100 oxygen atoms,[14a] as shown in Fig. 319.

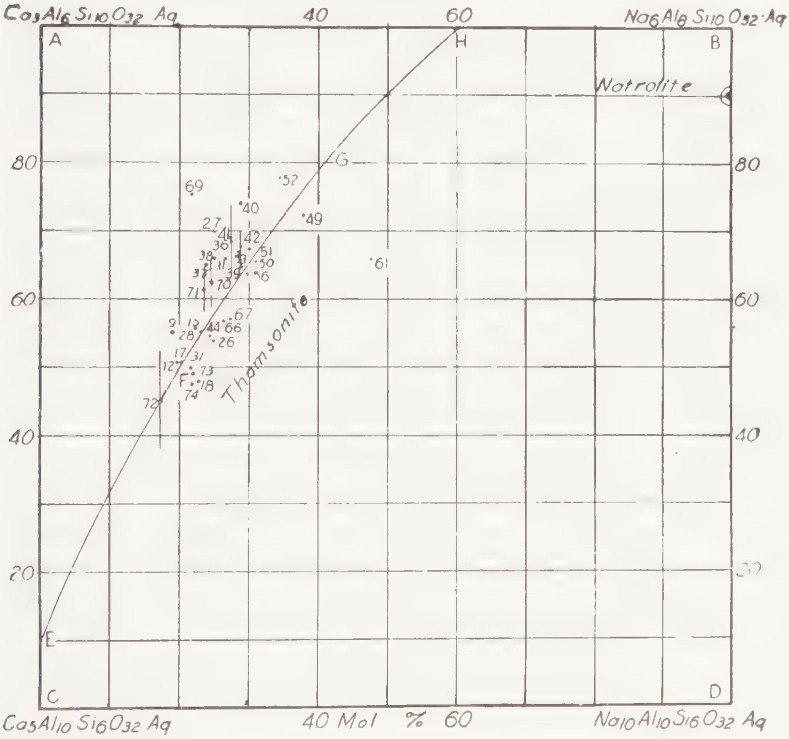

Fig. 319.—The composition of thomsonite.

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[14] *Am. Mineral.*, VIII, 1923, p. 121, and X, 1925, p. 342.

[14a] A. N. Winchell: *Am. Mineral.*, X, 1925, p. 88 and XI, 1926, p. 82.

THOMSONITE ORTH. $\left\{ \begin{array}{l} m\mathrm{Na_4Ca_8Al_{20}Si_{20}O_{80} \cdot 24H_2O} \\ + n\mathrm{Na_7Ca_5Al_{17}Si_{23}O_{80} \cdot 24H_2O} \end{array} \right.$

$a : b : c = 0.993 : 1 : 1.007$

PHYS. CHAR.—Euhedral crystals rare; habit prismatic to fibrous, vertically striated. Commonly lamellar parallel to 010; often radiated. Perfect 010 and imperfect 100 cleavages. H. = 5–5.5. G. = 2.25–2.40. F. = 2 with intumescence. Gelatinizes with HCl.

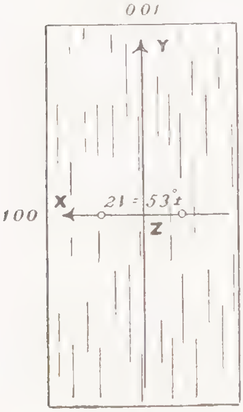

FIG. 320.—Optic orientation of thomsonite.

OPT. PROP.—The optic plane is 001 which is normal to the elongation; the acute bisectrix Z is normal to 010. (+) 2V = 54 ±, $\rho > v$ distinct, 2E = 80°–90°, $N_g = 1.518–1.542$, $N_m = 1.513–1.532$, $N_p = 1.512–1.530$, $N_g - N_p = 0.006–0.020$. Detailed data[15] are not available for a graph, but refringence and birefringence decrease as soda and silica increase; in general the optic angle probably decreases also, but Patton[16] has reported an increase with an increase of silica and soda.

Colorless, white, yellow, pink. Colorless in section.

OCCUR.—Always closely associated with other zeolites or prehnite in cavities in basic igneous rocks, schists, or contact altered limestones.

DIAG.—Characterized among the zeolites by its parallel extinction and ± sign of elongation.

Gonnardite ($\mathrm{NaCaAl_4Si_5 \cdot 5H_2O}$?) is orthorhombic fibrous with H. = 4.5–5. G. = 2.25. F. = easy with swelling. Gelatinizes with HCl. Natural flattening or cleavage normal to X; Z = c = elongation. (+) 2V = 52° ± 6°, $N_g = 1.520$, $N_m = 1.515$, $N_p = 1.514$, $N_g - N_p = 0.006$, all ± 0.005. Color white. Alters to a zeolite with negative elongation or to thomsonite. Found in cavities in basalt in France. Very rare.

Lintonite is chemically like thomsonite, but is reported to be nearly uniaxial and to have negative elongation with an extinction angle of about 19°. *Jacksonite* is similar, but has positive elongation and a very small extinction angle. Rare.

Chlorastrolite is chemically like thomsonite, but has an extinction angle ($Y \wedge c$) of 20° and is distinctly pleochroic from colorless to light green.

Epidesmine[17] ($\mathrm{CaAl_2Si_6O_{16} \cdot 6H_2O}$?) is chemically like stilbite (also called desmine) but is orthorhombic and prismatic or tabular. Good 100 and distinct 010 cleavages. G. = 2.16. F. = easy with intumescence. Optic plane is 100. X = c. (−)2V =

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[15] Data of Des Cloizeaux ($N_g = 1.525$, $N_m = 1.503$, $N_p = 1.496$) are considered incorrect by Böggild: *Kgl. Danske Vid. Selsk.*, IV, 1922, p. 41.

[16] *Bull. Geol. Soc. Amer.*, XI, 1900, p. 461.

[17] *Cent. Mineral.*, 1913, p. 422; S. G. Gordon: *Am. Mineral.*, V, 1920, p. 167.

40° ±. $N_g = 1.500$, $N_m = 1.495$, $N_p = 1.485$, $N_g - N_p = 0.015$. Colorless to yellow. Forms a crust on calcite with orthoclase and fluorite. Very rare.

Stellerite[18] ($CaAl_2Si_7O_{18}\cdot 7H_2O$?) is orthorhombic with $a : b : c = 0.98 : 1 : 0.76$. Perfect 010, distinct 100 and indistinct 001 cleavages. H. = 3.5–4. G. = 2.12. Optic plane is 010. X = c. (−) 2V = 44°, $\rho < v$, $N_g = 1.495$, $N_m = 1.49$, $N_p = 1.484$, $N_g - N_p = 0.011$. Color pink; colorless in section. Found in cavities in diabase. Very rare.

Erionite[19] ($KNaCaAl_4Si_{12}O_{32}\cdot 12H_2O$?) is orthorhombic and fibrous like wool. G. = 2.0. F. = easy to clear glass. Soluble in HCl. Optic plane and Z parallel to c (= elongation). (+) 2V = ?, $N_g = 1.452$, $N_m = 1.44$, $N_p = 1.438$, $N_g - N_p = 0.014$. Color white. Found in cavities in rhyolite in Oregon. Very rare.

Echellite[20] ($Na_2Ca_2Al_{12}Si_9O_{39}\cdot 12H_2O$?) is orthorhombic fibrous with H. = 5. If the perfect cleavage be taken as 010, the optic plane is 001 and X = b; sign of the fibrous vertical elongation is ±; (+) 2V = 50° ± 5°. $N_g = 1.545$, $N_m = 1.533$, $N_p = 1.530$, $N_g - N_p = 0.015$. Colorless or porcelain white. Found in basic intrusive rocks with calcite in Ontario. Very rare.

Ferrierite[21] ($Na_2MgAl_3Si_{15}O_{36.5}\cdot 9H_2O$?) is orthorhombic in 100 laths elongated vertically. 100 ∧ 101 = 67° 47′. Perfect 100 cleavage. H. = 3–3.5. G. = 2.15. F. = 3–3.5. Whitens in closed tube. Nearly insoluble in HCl. Optic plane is 010 and Z = c; (+) 2V = 50° 25′. $N_g = 1.482$, $N_m = 1.479$, $N_p = 1.478$, $N_g - N_p = 0.004$. Colorless to white. Exceptional as a zeolite in containing magnesium. Found in veins with chalcedony in olivine basalt at Kamloops, B. C. Very rare.

EDINGTONITE ORTH. $a : b : c = 0.987 : 1 : 0.673$ $BaAl_2Si_3O_{10}\cdot 3H_2O$

PHYS. CHAR.—Crystals minute pseudotetragonal with perfect 110 cleavages. H. = 4. G. = 2.7–2.78. F. = 5. Gelatinizes with acid.

OPT. PROP.—The optic plane is 010; X = c. (−) 2E = 87° ±, $\rho < v$ weak; 2V = 49°–53°. $N_g = 1.554$, $N_m = 1.549$, $N_p = 1.539$, $N_g - N_p = 0.015$.

Color white, grayish, pink; colorless in section.

OCCUR.—With thomsonite, analcite, etc., in Sweden. Very rare.

DIAG.—Refringence and birefringence high for a zeolite; optic sign and sign of elongation negative; crystals minute, pyramidal.

PTILOLITE ORTH. $a : b : c = 0.878 : 1 : 0.361$ $Na_3Ca_2Al_7Si_{33}O_{80}\cdot 25H_2O$?

COMP.—Analyses indicate an isomorphous series; formula derived from Kosmatt's analysis.[22]

PHYS. CHAR.—Crystals prismatic vertically striated. Cottony aggregates. Perfect 100 and distinct 010 cleavages. H. = 5. G. = 2.1. F. = 3–4 to clear glass. Insoluble in HCl.

OPT. PROP.—The optic plane is 100 and X = c; (−) 2V = 57° ±, $N_g = 1.473–1.482$, $N_m = 1.477$ ±, $N_p = 1.472–1.478$, $N_g - N_p = 0.002–0.003$. Colorless or white.

Crystals from Teigarhorn, Iceland, show extinction at small angles (1°–5°) on 010 and 100, suggesting a relationship to mordenite.

OCCUR.—In cavities in basalts, etc., with other zeolites, chalcedony, calcite. Rare.

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[18] *N. Jahrb. Min.*, 1910, II, p. 25.

[19] *Am. Jour. Sci.*, VI, 1898, p. 66.

[20] N. L. Bowen: *Am. Mineral.*, V, 1920, p. 1.

[21] R. P. D. Graham: *Trans. Roy. Soc. Canada*, Ser. 3, XII, 1918, p. 185.

[22] G. Tschermak: *Sitz. Akad. Wiss. Wien*, CXXVI, 1917, p. 547.

DIAG.—Differs from mordenite and heulandite in symmetry and from natrolite in optic signs.

NATROLITE

ORTHORHOMBIC $Na_2Al_2Si_3O_{10} \cdot 2H_2O$

$a : b : c = 0.978 : 1 : 0.354$

PHYS. CHAR. Crystals nearly always prismatic, vertically striated, much elongated, pseudotetragonal, acicular to fibrous; rarely elongated parallel to b. Rare twinning on 301 in penetration crosses, nearly rectangular. Microscopic twinning on 110; also 100. Perfect 110 cleavages and 010 parting. H. = 5–5.5. G. = 2.25. F. = 2. Gelatinizes with HCl.

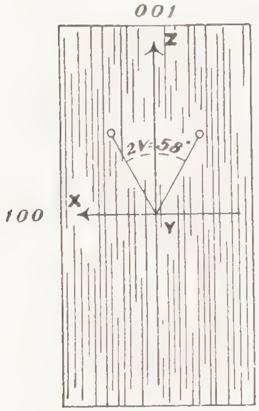

FIG. 321.—Optic orientation of natrolite.

OPT. PROP.—The optic plane is 010; the acute bisectrix X is normal to 001; the negative relief is distinct and the birefringence is greater than that of quartz.

(+) 2E = 90°–99°, $\rho < v$ weak, 2V = 60°–63°. $N_g = 1.485–1.493$, $N_m = 1.476–1.482$, $N_p = 1.473–1.480$, $N_g - N_p = 0.011–0.013$.

Color white, colorless, grayish, yellowish; colorless in section.

OCCUR.—In basic igneous rocks as an amygdaloidal filling; also, rarely, primary[23] (?) in basalt; also as an alteration product of nephelite, sedalite and plagioclase in syenite, diabase, etc.

DIAG.—Characterized by low refringence, parallel extinction and positive elongation and bisectrix.

SCOLECITE

MONOCLINIC $CaAl_2Si_3O_{10} \cdot 3H_2O$

$a : b : c = 0.974 : 1 : 0.343 \quad \beta = 90° 42'$

PHYS. CHAR.—Crystals slender prismatic vertically striated; commonly in fibrous masses. Twinning on 100; rarely on 110 and 001. Nearly perfect 110 cleavages. H. = 5. G. = 2.3. F. = 2, curling into worm-like forms (whence the name). Gelatinizes with HCl.

OPT. PROP.—The optic plane and Z are normal to 010; $X \wedge c$ = 15°–18° in the obtuse angle β. (−) 2V = 36°±, $\rho < v$, distinct. 2E = 36°–56°; Böggild[24] gives $N_g = 1.5194$, $N_m = 1.5187$, $N_p =$

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[23] S. Richarz; *Zt. Deut. Geol. Ges.*, LXXII, 1920, p. 1.

[24] *Zeit. Kryst.*, XLIII, 1907, p. 633.

1.5122, $N_g - N_p = 0.0072–0.0083$. Michel[25] gives $N_m = 1.515$, $N_p = 1.509$.

Colorless or white.

OCCUR.—In cavities in basic igneous rocks; also in schists and contact-altered limestones.

DIAG.—Scolecite differs from natrolite by its inclined extinction and negative elongation; from thomsonite by its weaker birefringence, inclined extinction and negative elongation; from mesolite by its stronger birefringence, larger extinction angle and negative elongation, and from stilbite by its larger extinction angle. The refringence (N_p) is very near that of cedar oil (1.512).

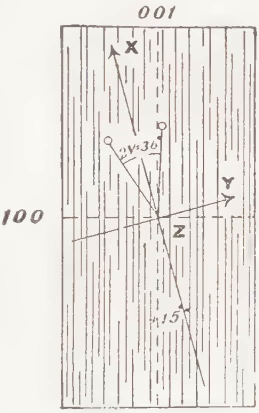

FIG. 322.—Optic orientation of scolecite.

LAUMONTITE SERIES

The accepted formula for laumontite is $CaAl_2Si_4O_{12}\cdot 4H_2O$ or $H_4CaAl_2Si_4O_{14}\cdot 2H_2O$. The best analyses show variation to an appreciable tenor of Na. The writer has presented the evidence[2] to show a simultaneous variation in the Al : Si ratio, as in feldspar, and therefore a series of the type indicated by the formulas given below.

LAUMONTITE MONO.

$a : b : c = 1.145 : 1 : 0.591$ $\beta = 68°46'$

$$\left\{ \begin{array}{l} mCa_7Al_{14}Si_{26}O_{80}\cdot 25H_2O \\ +nNa_2Ca_5Al_{12}Si_{28}O_{80}\cdot 25H_2O \end{array} \right.$$

PHYS. CHAR. Crystals prismatic somewhat like pyroxene. Twinning on 100. Perfect 010 and 110 cleavages. H. = 3–4. G. = 2.23–2.41. F. = 2.4 with swelling. Gelatinizes with HCl.

OPT. PROP.—The optic plane is 010; $Z \wedge c = 20°–40°$ in the acute angle β. Optic angle moderate with $\rho < v$, distinct, and weak inclined dispersion. (−) $2V = 52° 24'$ (red), $56° 15'$ (blue), $N_g = 1.525$, $N_m = 1.524$, $N_p = 1.513$, $N_g - N_p = 0.012$. Larsen[26] gives: $N_g = 1.517$, $N_m = 1.515$, $N_p = 1.505$, $N_g - N_p = 0.012$.

Color white, glassy, yellowish, grayish, etc.

ALTER.—Loses about one eighth of its water very easily, often simultaneously falling to a powder, and is then called *caporcianite*,

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[25] *Tsch. Min. Pet. Mit.*, XXX, 1911, p. 482.

[26] *Am. Mineral.*, VI, 1921, p. 6. See also H. W. McClellan: *Am. Mineral.*, XI, 1926, p. 287.

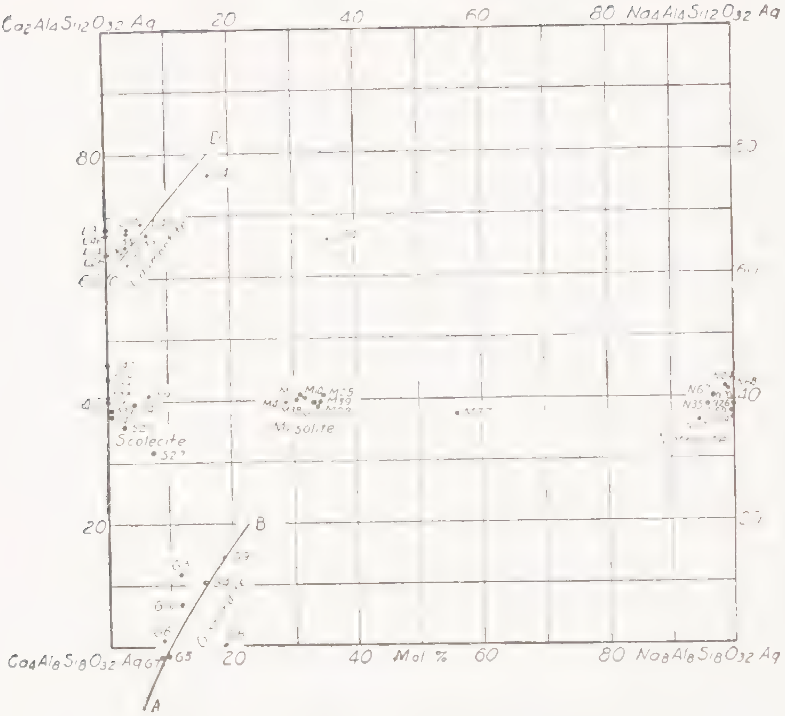

FIG. 323.—The composition of laumontite and related zeolites.

leonhardite or *β-leonhardite*. Larsen's data on indices probably refer to caporcianite, which has an extinction angle of 40° on prismatic cleavage pieces.[27]

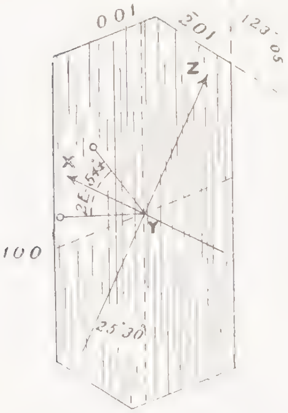

FIG. 324.—Optic orientation of laumontite.

OCCUR.—In veins in schists, slates, etc.; also in cavities in igneous rocks.

DIAG.—The perfect cleavages in three directions in one zone are quite distinctive. Further, the mineral has positive elongation with a large extinction angle, and stronger birefringence than phillipsite.

GISMONDITE SERIES

The formula of gismondite is commonly written as $CaAl_2Si_2O_8 \cdot 4H_2O$. The best analyses show K always present and variable to a considerable tenor. The writer [2] has presented the evidence to show a simultaneous variation in the Al : Si ratio, as in the feldspars, so that the mineral seems to form a series of the type indicated by the formulas given below.

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[27] T. L. Walker: *Univ. Toronto Studies, Geol. Series*, 14, 1922, p. 57.

GISMONDITE Mono. $\left\{\begin{array}{l} m\mathrm{KCa_{10}Al_{21}Si_{19}O_{80} \cdot 40H_2O} \\ +n\mathrm{K_4Ca_7Al_{18}Si_{22}O_{80} \cdot 36H_2O} \end{array}\right.$

$a : b : c = 0.956 : 1 : 0.319$, $\beta = 90° \pm$

Phys. Char.—Crystals pseudotetragonal bipyramids (terminal angle of 61°) produced by twinning on 110 and 001. Distinct 101 cleavage. H. = 4.5. G. = 2.27. F. = 3, with intumescence. Gelatinizes with HCl.

Opt. Prop.—Basal sections show four segments with opposite parts alike and extinction inclined at 5°. The edge of the pyramid corresponds with the clino-axis *a*. The optic plane and acute bisectrix X are normal to 010; Z is nearly normal to 100. Optic angle large. $(-)\ 2V = 82°–86°$, $N_g = 1.5484$, $N_m = 1.5402$, $N_p = 1.5308$ Na, $N_g - N_p = 0.0176$ (Hibsch [28]). $2V = 82°\ 43'$, $N_m = 1.5385$ Na (Rinne [29]), $N_g - N_p = 0.008$ (Lacroix [29a]). Colorless, white or grayish.

Occur.—In cavities in volcanic and other rocks, often with phillipsite. Rare.

Diag.—The external form is characteristic; the twinning is notable.

PHILLIPSITE SERIES

The formula of phillipsite is written: $\mathrm{(Ca,K_2)Al_2Si_4O_{12} \cdot 4.5H_2O}$, but the best analyses show considerable variation in the Al : Si ratio as well as in the Ca : K ratio. The writer has presented the evidence [9] to show that these variations are simultaneous, as in feldspar, and that the mineral forms a series of the type indicated by the formulas given below.

PHILLIPSITE Mono. $\left\{\begin{array}{l} m\mathrm{K_4Ca_7Al_{18}Si_{22}O_{80} \cdot 40H_2O} \\ +n\mathrm{K_6Ca_5Al_{16}Si_{24}O_{80} \cdot 30H_2O} \end{array}\right.$

$a : b : c = 0.5148 : 1 : 0.3547$ [30]

$\beta = 90° \pm$

Phys. Char.—Crystals always penetration twins apparently orthorhombic or tetragonal. Twinning on 100; also often on 120 as

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[28] *Tsch. Min. Pet. Mit.*, XXXIV, 1917, p. 187.

[29] *Zeit. Kryst.*, XX, 1892, p. 302.

[29a] *Minéraux des Roches*, 1888, p. 306.

[30] Orientation of G. Tschermak: *Sitz. Akad. Wiss. Wien*, CXXVI, 1917, p. 600. See stilbite for comparison with orientation of Dana.

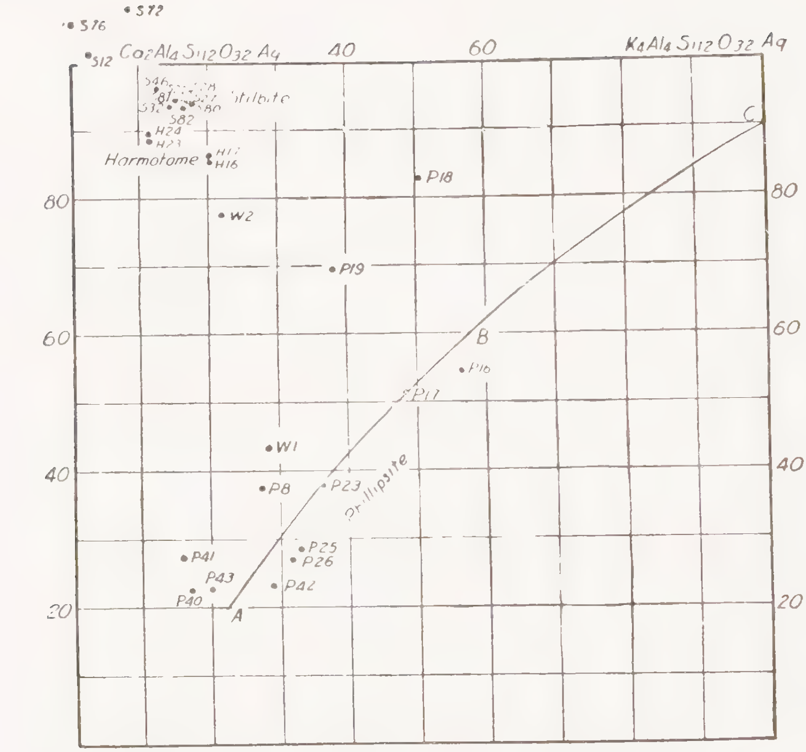

FIG. 325.—The composition of phillipsite and related zeolites.

rectangular crosses in two or three directions. Also in spherulites. Elongation parallel to *c*. Distinct 100 and 010 cleavages. H. = 4–4.5. G. = 2.2. F. = 3, to a white enamel. Gelatinizes with HCl.

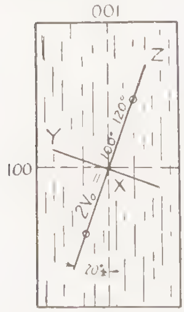

FIG. 326.—Optic orientation of phillipsite.

OPT. PROP.—The optic plane is normal to 010: $Z \wedge c = 10°$ to $30°$ in the acute angle β. In some cases apparently triclinic, since sections parallel to 100 give an extinction angle of 10° + on 010. Optic angle large, but variable. The relations between optic properties and composition are not well known, but apparently the most siliceous have the lowest index (about 1.48) with $Z \wedge c = 10° \pm$, and $N_g - N_p = 0.003$, while in the least siliceous types the index[31] reaches about 1.51, with $Z \wedge c = 30° \pm$, and $N_g - N_p = 0.010$. The optic angle varies from (+) $2V = 60°$ to (+) $2V = 80°$, and perhaps more.[32] Dispersion $\rho < v$ weak. Colorless, white: yellowish or reddish by staining.

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[31] The value 1.57 obtained by indirect methods by Des Cloizeaux is probably incorrect.

Occur.—In druses of basalt and other rocks; common in red clay and deep sea deposits; formed in some hot spring waters; often associated with chabazite; less frequently with thomsonite, calcite, apophyllite.

Diag.—The twinning of phillipsite is quite characteristic except as compared with harmotome, which is rare and has different optic orientation.

Wellsite is a rare barium-bearing phillipsite with complex twinning. G. = 2.28–2.37, H. = 4–4.5. F. = 3. Decomposed by HCl. Optic plane normal to 010; $X \wedge c = 4°$, (+) $2V = 39° \pm$, $N_g = 1.503$, $N_m = 1.50$, $N_p = 1.498$, $N_g - N_p = 0.005$. Colorless. Rare.

HARMOTOMITE (*Harmotome*) Monoclinic $KBa_5Al_{11}Si_{29}O_{80} \cdot 25H_2O$?

$a : b : c = 0.505 : 1 : 0.352$ [33] $\beta = 90° \pm$

Phys. Char.—Crystals much like those of phillipsite, elongated parallel to c. Distinct 010 and indistinct 100 cleavages. Cruciform twins. H. = 4.5. G. = 2.44–2.50. F. = 3.5 without intumescence to white glass. Decomposed by HCl.

Opt. Prop.—The optic plane is normal to 010; $X \wedge c = 62°$. Optic angle large with weak crossed dispersion. (+) $2V = 43°$, $N_g = 1.508$, $N_m = 1.505$, $N_p = 1.503$, $N_g - N_p = 0.005$. Colorless or white.

Occur.—In cavities in basalt and other rocks; also in lead and zinc veins.

Diag.—Distinguished from phillipsite by greater specific gravity, due to the barium, and by different optic orientation.

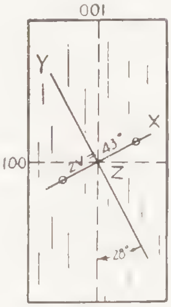

Fig. 327.—Optic orientation of harmotomite.

STILBITE

Monoclinic $Na_3Ca_9Al_{21}Si_{59}O_{160} \cdot 60H_2O$?

$a : b : c = 0.463 : 1 : 0.381$ [34] $\beta = 89° 30'$

Phys. Char.—Crystals always twinned as crosses on 100 to pseudo-rhombic forms. Usually flattened parallel to 010 and always elongated

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[32] S. Richarz (*Zeit. Dtsch. Geol. Ges.*, LXXII, 1920, p. 1) reports phillipsite of negative sign with $2V = 60°–65°$ and $Z \wedge c = 24°–25°$.

[33] Orientation of G. Tschermak: *Sitz. Akad. Wiss. Wien*, CXXVI, 1917, p. 600. See stilbite for comparison with orientation of Dana.

[34] Orientation of G. Tschermak: *Sitz. Akad. Wiss. Wien*, CXXVI, 1917, p. 600. A comparison with Dana's orientation follows:

Dana	Tschermak	Dana	Tschermak
001 =	100	$\bar{1}01$ =	001
010 =	010	011 =	120
100 =	$10\bar{1}$	110 =	$12\bar{1}$

Stilbite is regarded as orthorhombic by Goldschmidt, and by Shannon (*Proc. U. S. Nat. Mus.*, LXVI, 1924, p. 72), with abnormally inclined extinction in many cases.

parallel to *c*. Often in sheaf-like aggregates. Perfect 010 and indistinct 100 cleavages. H. = 3.5–4. G. = 2.09–2.20. F. = 3, with exfoliation, to white enamel. Decomposed by HCl.

OPT. PROP.—The optic plane is parallel to 010 and $X \wedge c = 5°$ (3°–12°); the optic angle is not large. (−) $2V = 33° \pm$, $\rho < v$. $N_g = 1.500$, $N_m = 1.498$, $N_p = 1.494$, $N_g - N_p = 0.006$ (Lacroix[35]), $N_g = 1.504$, $N_m = 1.501$, $N_p = 1.493$, $N_g - N_p = 0.011$ (Müller[36]), $N_g = 1.508$, $N_m = 1.504$, $N_p = 1.500$, $N_g - N_p = 0.008$ (Shannon[37]).

Color white or yellowish. Colorless in section.

OCCUR.—In cavities in basaltic rocks and fractures in other rocks; also in some hot spring deposits.

DIAG.—Differs from phillipsite and harmotomite by its lamellar aggregates and cleavage, as well as by its extinction angles and sign of elongation. Differs from heulandite in sign and optic orientation.

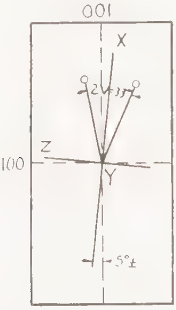

FIG. 328.—Optic orientation of stilbite.

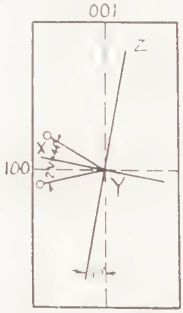

FIG. 329.—Optic orientation of epistilbite.

EPISTILBITE MONO. $a : b : c = 0.419 : 1 : 0.432$[38] $NaCa_5Al_{11}Si_{29}O_{80} \cdot 25H_2O$?
$\beta = 89° 20'$

COMP.—No modern analyses are known.

PHYS. CHAR.—Crystals always prismatic, twinned; radiated spherical aggregates. Twinning on 100 or 110 may form penetration crosses. Perfect 010 cleavage. H. = 4. G. = 2.25. F. = 3 with intumescence. Decomposed by HCl.

OPT. PROP.—The optic plane is 010 and $Z \wedge c = 10°$ in the acute angle β. The vertical elongation is positive. (+) $2E = 69°–73°$ Li, $72°–77°$ Tl, $N_g = 1.512$, $N_m = 1.510$, $N_p = 1.502$, $N_g - N_p = 0.010$.

Colorless, white or pinkish; colorless in section.

OCCUR.—Often associated with stilbite, etc., in cavities in rocks.

DIAG.—Differs from stilbite and mesolite in the sign of elongation, and has a smaller extinction angle than phillipsite.

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[35] *Minéraux des Roches*, 1888, p. 319.

[36] *N. Jahrb. Min. Beil. Bd.*, XLIV, 1921, p. 415.

[37] *Proc. U. S. Nat. Mus.*, LXVI, 1924, p. 72.

[38] Ratios and orientation of Tschermak (*Sitz. Akad. Wiss. Wien*, CXXVI, 1917, p. 601) adopted to show the relation between epistilbite and heulandite.

BREWSTERITE MONOCLINIC $Na(Sr,Ba,Ca)_5Al_{11}Si_{29}O_{80} \cdot 25H_2O$?

$a : b : c = 0.405 : 1 : 0.420. \quad \beta = 86° 20'$

PHYS. CHAR.—Crystals commonly prismatic, somewhat vertically elongated and striated, and flattened parallel to 010. Perfect 010 cleavage. H. = 5. G. = 2.45. F. = 3, with swelling. Decomposed by HCl.

OPT. PROP.—The optic plane is normal to 010 and $X \wedge c = 22°$ in the obtuse angle β; the extinction angle varies from 19° to 34° in various parts of zonal crystals. (+) $2V = 65° \pm$, $\rho > v$ weak; also weak crossed dispersion. $N_g = 1.523$, $N_m = 1.512$, $N_p = 1.510$, $N_g - N_p = 0.013$ (Larsen [39]).

Color white, yellowish or greenish.

OCCUR.—In drusy cavities in schists and basalts. Rare.

DIAG.—Differs from heulandite and epistilbite in optic orientation.

HEULANDITE SERIES

The accepted formula of heulandite is $CaAl_2Si_6O_{18} \cdot 5H_2O$ or $H_4CaAl_2Si_6O_{18} \cdot 3H_2O$. The best analyses show that Na is probably always present, but is variable in amount. The writer has presented the evidence [2] to show that there is a simultaneous variation in the

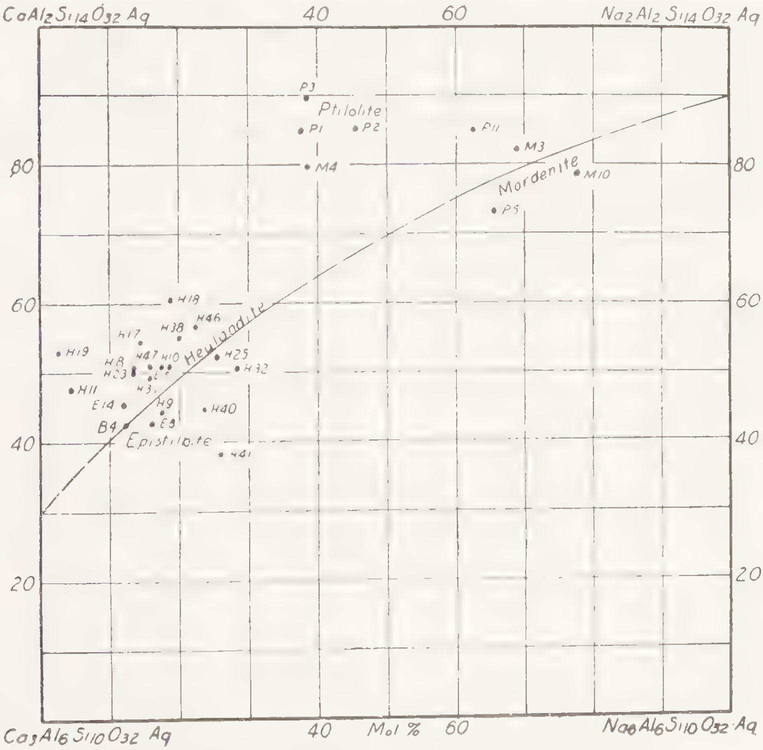

FIG. 330.—The composition of heulandite and related zeolites.

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[39] Personal communication, Sept. 18, 1925.

Al : Si ratio so that the mineral forms a series of the feldspar type as indicated by the formulas given below.

HEULANDITE MONO. $\left\{ \begin{array}{l} m\mathrm{NaCa_5Al_{11}Si_{29}O_{80}\cdot 25H_2O} \\ +n\mathrm{Na_2Ca_4Al_{10}Si_{30}O_{80}\cdot 25H_2O} \end{array} \right.$

$a : b : c = 0.403 : 1 : 0.429, \beta = 88°34'$

PHYS. CHAR.—Crystals often 010 tablets or nearly equant, of orthorhombic aspect. Aggregates of nearly parallel units. Perfect 010 cleavage. H. = 3.5–4. G. = 2.2. F. = 2, with swelling to vermicular forms. Decomposed by HCl.

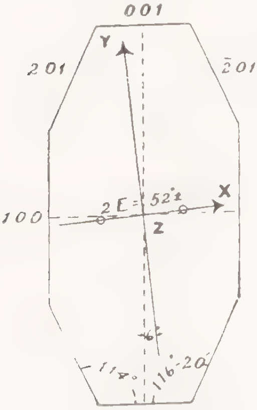

FIG. 331.—Optic orientation of heulandite.

OPT. PROP.—The optic plane is normal to 010 and varies from nearly parallel to nearly normal to 001. Z = b, Y $\wedge$ c = 6°, but very variable. (+) 2E = 0°–92°, usually near 50°, 2V = 34° ±, $\rho > v$, $N_g = 1.505$, $N_m = 1.499$, $N_p = 1.498$, $N_g - N_p = 0.007$. Crystals from Nova Scotia have $N_g = 1.501$, $N_m = 1.497$, $N_p = 1.496$, $N_g - N_o = 0.006$ (Parsons[40]). Crystals from Pangelberg, Silesia[41] have the optic plane parallel to 001 for a color between Na and Li light, with 2E = 51° 49' Na. Crystals from Iceland[42] have: X $\wedge$ a = 20°–22° in the obtuse angle β; (+) 2E = 74° 38', $N_g = 1.5052$, $N_m = 1.5008$, $N_p = 1.4991$, $N_g - N_p = 0.0061$.

Color white, yellowish or stained gray, brown or red.

OCCUR.—Especially in cavities in basalts; also in schists; usually with other zeolites.

DIAG.—Heulandite is rarely fibrous, but has a lamellar cleavage with the positive acute bisectrix normal thereto. Epistilbite, mordenite and brewsterite are similar, but differ in optic orientation.

MORDENITE MONO. $a : b : c = 0.401 : 1 : 0.428$ $\mathrm{Na_4Ca_2Al_8Si_{32}O_{80}\cdot 25H_2O}$?
$\beta = 88° 30'$

PHYS. CHAR.—Crystals often 010 tablets; also in groups parallel to 010; also fibrous radially arranged. Perfect 010 cleavage. H. = 3–4. G. = 2.08–2.15. F. = 4–5 with intumescence. Partly decomposed by HCl.

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[40] *U. Toronto Stud. Geol. Ser.* 14, 1922, p. 52.

[41] O. Tietze: *Jahrb. preuss. Geol. Landes*, XXXVI, 1915, p. 398.

[42] C. B. Slawson: *Am. Mineral.*, X, 1925, p. 305, and personal communication, Nov. 9, 1926.

OPT. PROP.—The optic plane and X are normal to 010; $Z \wedge c = 73\frac{1}{2}°$ in the acute angle β (Pirsson [43]); $Z = b$, $X \wedge c = 4°$ (Ross [44]). Optic angle large; optic sign positive. $N_m = 1.465$, $N_g - N_p = 0.005$ (Larsen); $N_g = 1.476$, $N_m = 1.475$, $N_p = 1.471$, $N_g - N_p = 0.005$ (Ross [44]). Color white, yellowish, pinkish.

OCCUR.—In basalt in Nova Scotia and Wyoming. Rare.

DIAG.—Differs from heulandite in optic orientation and lower refringence.

Laubanite ($Ca_2Al_2Si_5O_{15} \cdot 6H_2O$?) is fibrous and perhaps monoclinic, although apparently uniaxial. Good prismatic cleavage. H. = 4.5. G. = 2.2. Fuses to a blebby glass. Gelatinizes with HCl. (+) $2V = 0°$, $N_g = 1.486$, $N_m = N_p = 1.475$, $N_g - N_p = 0.011$. Color white. With phillipsite in basalt. Rare.

Bavenite ($Ca_3Al_2Si_6O_{18} \cdot H_2O$?) is monoclinic with $a : b : c = 1.175 : 1 : 0.784$, $\beta = 89° 17'$. Insufficient water for a typical zeolite. Fibers apparently orthorhombic, flattened parallel to 100. Distinct 010 cleavage. Twinning on 100. H. = 5.5. G. = 2.72. Optic plane and Z normal to 010; $X \wedge a = 2°$. (+) $2V = 47°$, $N_g = 1.583$, $N_m = 1.579$, $N_p = 1.578$, $N_g - N_p = 0.004$. Found in pegmatitic druses in Italy. Rare.

MESOLITE TRICLINIC $a : b : c = 0.975 : 1 : 0.312$ $Na_2Ca_2Al_6Si_9O_{30} \cdot 8H_2O$
$\alpha = ?$ $\beta = 92°$ $\gamma = ?$

PHYS. CHAR.—Commonly fibrous in divergent groups; twinning constant on 100, only visible microscopically. Perfect 110 and $1\bar{1}0$ and less distinct 001 cleavages. H. = 5. G. = 2.27. F. = easy with swelling to vermicular forms. Gelatinizes with HCl.

OPT. PROP.—The optic plane is nearly normal to 010 and to the elongation (c) of the fibers; Z nearly normal to 010; $Y \wedge c = 1\frac{1}{2}°–5°$; $X \wedge a = 7° \pm$; birefringence very weak. (+) $2V$ = about 80° at 15° C. with $\rho < v$ strong, but changes rapidly upon heating [11] so that 2V about Z is more than 90° for blue at 20° C., and more than 90° for all colors at 30°C. $N_g = 1.5053$, $N_m = 1.5050$, $N_p = 1.5048$, $N_g - N_p = 0.0005$ (Görgey [45]).

Colorless, white, grayish or yellowish.

OCCUR.—In cavities in basic igneous rocks.

DIAG.—Differs from natrolite and scolecite by the varying sign of elongation, and from other fibrous zeolites by the same character, the weak birefringence and the small extinction angle measured on the fibers.

Pseudomesolite is chemically like mesolite, but optically different; form like that of mesolite, but twinning unknown; distinct prismatic cleavages; $Z \wedge c = 20°$, and X and Y in such a position as to give extinction sensibly parallel with the diagonals of the rhombs formed by the prism faces in cross sections. Optic angle small about Z; birefringence very weak; relief negative. Color porcelain white or stained pinkish or greenish. Found in cavities in igneous rocks of Minnesota; rare. It differs from mesolite in the sign of elongation, the large extinction angle and the very small optic angle. It is possible that pseudomesolite is a partially dehydrated (above 35° C.) mesolite, but Görgey found no increase in the extinction angle at any temperature up to 130° C.

13. COMPOUNDS CONSISTING OF SILICATES WITH SALTS OF ANOTHER OXYGEN ACID

Schallerite [1] ($9MnSiO_3 \cdot Mn_3As_2O_8 \cdot 7H_2O$?) is tetragonal or hexagonal. Massive with perfect basal cleavage. H. = 4.5-5. G. = 3.37. F. = 5-6. Decomposed by HCl.

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[43] *Am. Jour. Sci.*, CXL, 1890, p. 232.

[44] *U. S. Nat. Mus. Proc.*, LXIV, 1924, Art. 19; *U. S. N. M. Bull.* 131, 1926, p. 346.

[45] R. Görgey: *Tsch. Min. Pet. Mit.*, XXVIII, 1909, p. 77.

[1] R. B. Gage, E. S. Larsen and Helen Vassar: *Am. Mineral.*, X, 1925, p. 9.

Uniaxial negative with $N_o = 1.704$, $N_e = 1.679$, $N_o - N_e = 0.025$. Color light brown in mass. Found at Franklin, N. J., with zinc ores. Very rare.

Wilkeite ($19CaO \cdot CO_2 \cdot 3P_2O_5 \cdot 3SO_3 \cdot 3SiO_2?$) is hexagonal with $c = 0.73$; probably related to the apatite group. Crystals prismatic without cleavage. H. = 5. G. = 3.23. F. = 5.5. Soluble in HCl. Uniaxial negative with $N_o = 1.655$, $N_e = 1.650$, $N_o - N_e = 0.005$. Color rose-red or yellow. Found in contact limestone. Very rare.

Cenosite (*Kainosite*) $\{2CaO \cdot (Y,Er)_2O_3 \cdot CO_2 \cdot 4SiO_2 \cdot 2H_2O?\}$ is orthorhombic with $a : b : c = 0.952 : 1 : 0.883$. Crystals short prismatic with one distinct cleavage. H. = 5.5. G. = 3.34–3.41. F. = 6. Soluble in HCl. (−) 2V = medium, $N_g = 1.683$, $N_m = 1.681$, $N_p = 1.667$, $N_g - N_p = 0.016$ (Larsen); (−) 2E = 78°, $N_g = 1.683$, $N_m = ?$, $N_p = 1.633$, $N_g - N_p = 0.05$ (Schetelig [2]). Color yellow to chestnut brown, not pleochroic. Found in an ore deposit. Very rare.

Roeblingite ($H_{10}Ca_7Pb_2S_2Si_5O_{28}?$) is probably orthorhombic in fibrous masses. H. = 3. G. = 3.43. F. = 3. Gelatinizes with acid. Parallel extinction and negative elongation. (+) 2V = small, $N_g = 1.66$, $N_m = 1.64$, $N_p = 1.64$, $N_g - N_p = 0.02$. Colorless. Found in a contact ore deposit. Very rare.

Chapmanite [3] ($5FeO \cdot Sb_2O_5 \cdot 5SiO_2 \cdot 2H_2O$) is orthorhombic; crystals lath-shaped. G. = 3.58. Elongation positive. Optically negative with $N_g = 1.96$, $N_m = ?$, $N_p = 1.85$, $N_g - N_p = 0.11$. Color olive green. Found in silver ores at Cobalt, Ont. Very rare.

Ardennite $\{H_6Mn_5Al_5(As,V)Si_5O_{28}?\}$ is orthorhombic with $a : b : c = 0.466 : 1 : 0.314$. Crystals prismatic with perfect 010 and distinct 110 cleavages; also 001 parting. H. = 6–7. G. = 3.6–3.65. F. = 2–2.5. Insoluble in HCl. Optic plane is 100; Z = b (Lasaulx); optic plane is 010; Z = c (Lacroix). (+) 2V = 68°–70° (Lacroix), 0°–50° (Larsen), $\rho > v$ very strong. N_m is estimated at 1.79 ± to 2.0 ± by Larsen; $N_g - N_p = 0.020$ (Lacroix); $N_g - N_p = 0.015$ (Larsen). Color yellow to brown with X = dark brownish yellow, Y = golden yellow, Z = pale yellow. Found in veins and pegmatite. Very rare.

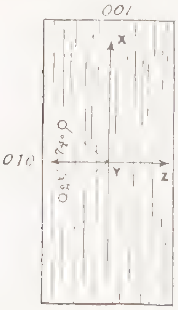

FIG. 332.—Optic orientation of ardennite.

Uranophanite ($CaU_2Si_2O_{11} \cdot 7H_2O$) is apparently orthorhombic [4] and fibrous. Crystals prismatic with one cleavage or flat face. H. = 2–3. G. = 3.8–3.96. F. = 7. Gelatinizes with HCl. X normal to cleavage or flat face; Z = c (elongation). (−) 2V = 32°–45°, $\rho < v$, extreme. $N_g = 1.669$, $N_m = 1.666$, $N_p = 1.643$, $N_g - N_p = 0.026$. Abnormal blue interference color due to strong dispersion. Color yellow with X = nearly colorless, Y = pale canary yellow, Z = canary yellow. Found in pegmatite; Very rare. *Uranotilite* may be different since it is said to be triclinic with $a : b : c = 0.626 : 1 : 0.594$, $\alpha = 87° 41'$, $\beta = 85° 18'$, $\gamma = 96° 31'$. Good 100 cleavage. X normal to cleavage. (−) 2V = ?, N = 1.671. Rare.

Sklodowskite [5] ($MgU_2Si_2O_{11} \cdot 7H_2O$) is orthorhombic in long prisms. G. = 3.54. Basal cleavage. Gelatinizes with HCl. Contains some Ni, K and Na. Optic plane is 001. (−) 2V = very large, $\rho < v$ distinct. $N_g = 1.657$, $N_m = 1.635$, $N_p = 1.613$, N_g

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[2] *Viden. Skr. I Mat. nat. Kl.*, 1922, No. 1, p. 124.

[3] T. L. Walker: *U. Toronto Studies, Geol. Ser.* 17, 1924, p. 5.

[4] A. Schoep: *Min. Abst.*, I, 1921, p. 244. See also *Am. Mineral.*, XI, 1926, p. 155.

[5] A. Schoep: *Bull. Soc. Fr. Min.*, XLVII, 1924, p. 162. Uranophanite and sklodowskite may be considered silicates of hexavalent and divalent bases rather than uranate-silicates.

$- N_p = 0.044$. Color yellow with X = colorless, Y = pale yellow, Z = yellow. Found in uranium ore in the Congo. Very rare.

Katoptrite[6] $\{14(Mn,Mg,Fe)O \cdot 2(Al,Fe)_2O_3 \cdot Sb_2O_3 \cdot 2SiO_2\}$ is monoclinic with $a : b : c = 0.792 : 1 : 0.490$, $\beta = 78° 57'$. Crystals 010 tablets with perfect 100 cleavage. H. = 5.5. G. = 4.5. Insoluble in acid. Optic plane is 010; $X \wedge c = 14°-15°$ with strong inclined dispersion. $(-)\ 2V = 25° \pm$, $\rho > v$. $N_m = 1.9$ (est.), $N_g - N_p = ?$. Color black; luster metallic; in section pleochroic red-brown to red-yellow parallel to Y. Found in contact deposits in limestone. Very rare.

Woehlerite $\{Ca_2Si_2O_6 \cdot mNa_2Nb_2O_6 \cdot nNa_2Zr_2O_4F_2(?)\}$ is monoclinic with $a : b : c = 1.055 : 1 : 0.709$, $\beta = 70° 45'$. Crystals prismatic and 100 tablets; twinning on 100. Distinct 010 cleavage. H. = 5.5–6. G. = 3.42. F. = 3–3.5. Soluble in HCl. Optic plane normal to 010; $X \wedge c = -45° \pm$. $(-)\ 2V = 71°$ to $79°$, $\rho < v$ distinct, $N_g = 1.726$, $N_m = 1.716$, $N_p = 1.700$, $N_g - N_p = 0.026$. Color light yellow to brown with X and Y = light wine yellow, Z = deep wine yellow. Found in zircon syenite. Very rare.

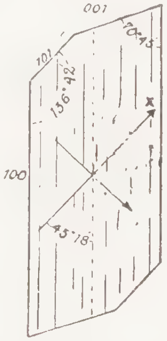

Fig. 333.—Optic orientation of woehlerite.

Epistolite $(H_7Na_6Cb_3TiSi_5O_{26}?)$ is monoclinic with $a : b : c = 0.803 : 1 : 1.206$, $\beta = 74° 42'$. Crystals 001 plates with perfect 001 and distinct 110 cleavages. H. = 1–1.5. G. = 2.89. Optic plane is 010; $Z \wedge c = +7° \pm$ with perceptible dispersion. $(-)\ 2V = 80° \pm$, $\rho < v$. $N_g = 1.682$, $N_m = 1.650$, $N_p = 1.610$, $N_g - N_p = 0.072$. Color white, yellow, gray; colorless in section. Found in pegmatite in Greenland. Very rare.

Spurrite $(5CaO \cdot CO_2 \cdot 2SiO_2)$ is monoclinic (?) with distinct 001 and indistinct 100 cleavages at 79°. Multiple twinning on 001 and on an orthodome at 57°. H. = 5. G. = 3. F. = 7. Effervesces and gelatinizes with HCl. Optic plane normal to 010; $Z \wedge a =$ nearly 0° with distinct crossed dispersion. $(-)\ 2V = 39\frac{1}{2}°$, $\rho > v$ weak. $N_g = 1.679$, $N_m = 1.674$, $N_p = 1.640$, $N_g - N_p = 0.039$. Tinted or colorless in mass. Found in a contact zone. Very rare.

Kasolite[7] $(3PbO \cdot 3VO_3 \cdot 3SiO_2 \cdot 4H_2O)$ is monoclinic with $a : b : c = 1.857 : 1 : 1.622$. $\beta = 76° 20'$. Perfect 001 and imperfect 100 and 010 cleavages. H. = 4–5. G. = 5.96. F. = easy. Gelatinizes with acid. Optic plane normal to 010; $Z \wedge c =$ nearly 0°. $(+)\ 2V = 39°$, $N > 1.78$. Color yellow. Found in ore deposits in the Congo. Very rare.

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[6] G. Flink: *Geol. För. Förh.*, XXXIX, 1917, p. 431.

[7] A. Schoep: *Comp. Rend.* CLXXIII, 1921, p. 1476; H. Buttengenbach: *Bull. Acad. Belg.*, 1922, p. 573.

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